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ABSTRACT

Designed to accompany the student text on the nervous system, this manual presents laboratory activities dealing with concepts presented in the text. Thirty-seven activities are described. Four supplementary activities dealing with concepts in electricity are also included. Laboratory activities are divided into several parts, each part covering a specific experiment dealing with the concept covered by the activity. Each part includes discriptions of materials, procedures, and discussion questions. (RE)

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BIOMEDICAL SCIENCE

UNIT IV

THE NERVOUS SYSTEM IN HEALTH AND MEDICINE

THE NERVOUS SYSTEM; DISORDERS OF THE
BRAIN AND NERVOUS SYSTEM; APPLICATION
OF COMPUTER SCIENCE TO DIAGNOSIS; DRUGS
AND PHARMACOLOGY; THE HUMAN SENSES;
ELECTRICITY

LABORATORY MANUAL
REVISED VERSION, 1976

THE BIOMEDICAL INTERDISCIPLINARY CURRICULUM PROJECT
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LABORATORY ACTIVITY 1: OBSERVING THE BRAIN

INTRODUCTION:

While there are major differences between them, the human brain resembles the brains of other animals in many ways. Therefore, by studying the brains of other animals, one can obtain information about the structure of the human brain. The study of the brain's blood vessels is particularly important in medicine because atherosclerosis of the arteries that supply the brain with blood is one of the leading causes of death in the United States.

In Part I of this activity, you will familiarize yourself with the structure of the brain of an animal and the functions of some of its parts. In Part II, you will make a microscopic observation of nervous tissue.

PART I: THE SURFACE OF THE BRAIN

MATERIALS:

- brain for dissection
- dissecting probe
- pan or aluminum foil
- scalpel or single-edged razor blade

PROCEDURE:

1. Familiarize yourself with the two surfaces of the brain: the top surface and the base. The top surface of a human brain is shown in Section 1, Figure 1, of the Student Text. This is the surface that is protected by the dome of the skull. The base is the other side of the brain.

2. Observe the top surface. Note the thin membrane closely covering the surface of the brain. Also note the numerous blood vessels on the surface. Is the color of the blood lifelike? (1) Are the blood vessels above or beneath the membrane? (2)

3. The largest, round part of the brain is the cerebrum. In back of the cerebrum find a smaller ball called the "cerebellum." The underside of the cerebellum is attached to the brain stem, a thick stalk. Find the brain stem.

4. The front of the brain stem merges into the base of the cerebrum. The back of the brain stem merges into the base of the cerebellum. As it leaves the rest of the brain, the brain stem merges into the narrower spinal cord. The spinal cord is generally cut off in preparation, leaving a stump. In some specimens, even the stump may be absent. Is the brain stem covered by a membrane? (3) Look for small white string-like structures on the sides of the brain stem. These are nerves.

*5. Use your dissecting probe to determine whether or not the cerebellum merges directly with the cerebrum. Do this by cutting through the membrane between the two. Are the cerebrum and cerebellum directly connected? (4) If not, what structure connects them? (5)

6. Notice that the surface of the cerebrum is covered with long twisting "hills" separated by "valleys." Compare and contrast the surface of the cerebellum to the surface of the cerebrum. (6)

7. Notice that the cerebrum consists of two hemispheres, the right and the left. They are separated by a large valley called a fissure. In general, the right hemi-

sphere controls the movements of the left side of the body, while the left hemisphere controls the movements of the right side of the body. This means that nerve cells from one hemisphere must go over to the opposite side of the body. The place where they cross over to the opposite side is in the brain stem and also in a struture in the cerebrum we will look at later.

The rear surface of the cerebrum,near the cerebellum, is devoted to vision in humans as well as in other animals. The middle surface of the cerebrum controls movements, and receives information on body movement and touch.

8. Look into the gap between the cerebellum and cerebrum for the round "bumps" on the brainstem. They are where nerve cells from the eyes and ears connect to other nerve cells that go to the cerebrum.

* 9. Cut a deep groove down the middle of the cerebellum from front to back. (Figure 1). Gently fold the cut surfaces apart to examine them. The white branches on the cut surfaces were called the "tree of life" by medieval scientists. These branches are made of thousands of axons (long parts of nerve cells)running parallel to each other. These nerve cells go from the cerebellum to the brain stem and then to other parts of the brain, helping to coordinate control over movements.

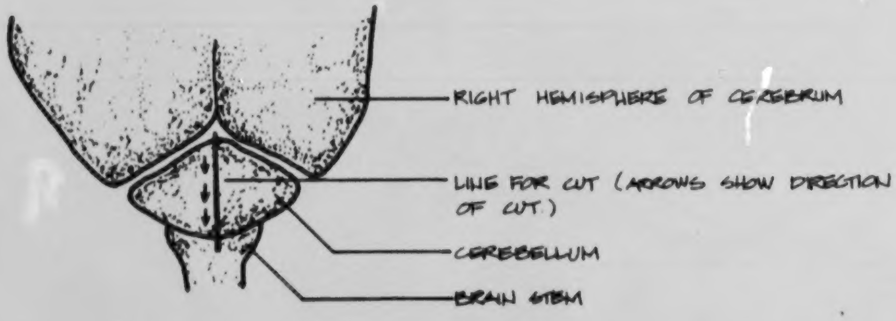

RIGHT HEMISPHERE OF CEREBRUM
LINE FOR CUT (ARROWS SHOW DIRECTION OF CUT)
CEREBELLUM
BRAIN STEM

FIGURE 1: Making the cut in the cerebellum.

*10. Make a cut into one cerebral hemisphere about 5 cm long and 2 cm deep. Examine the cut surfaces.

As in the cerebellum, the white areas are the axons (long parts) of nerve cells (Figure 2). Nerve cells also possess a small swelling called a "cell body," which contains the nucleus of the cell. Nerve cells are unlike any other kind of cells in the body.

The white areas on the cut surfaces of the cerebrum and cerebellum consist of billions of axons. The darker-shaded areas around the white branches in the cerebellum and on the surface of the cerebrum consist of cell bodies. Scientists have long called these white and darker-shaded areas "white matter" and

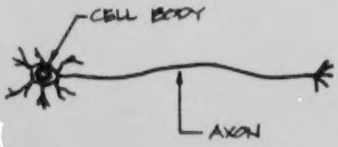


FIGURE 2: A nerve cell.

"gray matter" because of their color (Figure 3).

11. Now turn the brain over so that its base is exposed. Look at the smooth projections at the front of each hemisphere. They are involved in the sense of smell. They are called olfactory bulbs. Some animals have much larger olfactory bulbs than humans. This suggests that the sense of smell is (more, less) developed in humans than in animals with larger olfactory bulbs. (7)

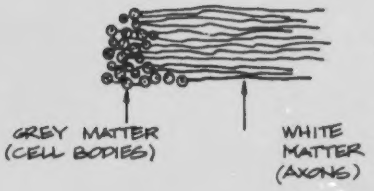


FIGURE 3: Nerve cells arranged into gray matter and white matter.

12. Compare the outside of the top surface of the brain to the pictures of the human brain in Section 1. In which is a larger proportion of the brain taken up by the cerebrum? (8)

13. Look again at the base. Note the white "x-shaped" structure in the middle. It is where the nerves from each eye cross each other. The name of this structure comes from the Greek name for the letter "χ." It is called the "optic chiasm" (KI-az-um). (The Greek name for the letter "χ" is "chi," as in the chi-square method.)

Find the two cut ends of the chiasm. These are the cut ends of the nerves that come from the eyes.

14. Right behind the chiasm is a bean-sized ball, the pituitary gland (Figure 4 and Figure 5). Figure 4 is a side view of the circled portion in Figure (5). (It may be missing in some specimens as a result of processing.) If it is present, find the small stalk connecting the pituitary gland to the brain. Notice the sponge-like mass of blood vessels attached to the pituitary gland. They insure that the hormones it produces gain quick access to the bloodstream.

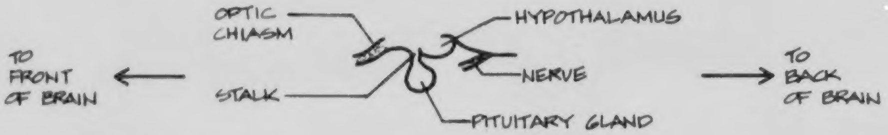


FIGURE 4: A side view of the pituitary gland.

15. Now locate the small ball that is partly tucked into the brain about 1 cm in back of the chiasm. This is part of the hypothalamus. The hypothalamus controls thirst and body temperature and also produces hormones that are stored in the pituitary gland.

16. Look at the brain stem. We will now consider a portion of the brain stem: the medulla. This part is shown in Section 1, Figure 5 of the Student Text. The medulla contains nervous tissue that controls the heartbeat, blood-vessel constriction, and respiration.

17. Notice all the large blood vessels on the base of the brain. Find a vessel which, if it were clogged by atherosclerosis, would affect circulation in the medulla.

Find a vessel near the optic chiasm which supplies the middle portion of one hemisphere with blood. If the corresponding vessel in a human brain becomes blocked, would the effect be more likely to be loss of vision or paralysis? (9)

Find a vessel of the brain which, if clogged by atherosclerosis, would affect vision.

18. Running along the sides of the brain stem are the stumps of nerves that have been cut. Like the white matter, they are made of numerous parallel axons. Notice that the nerves come in pairs. Find as many pairs of nerves as you can.

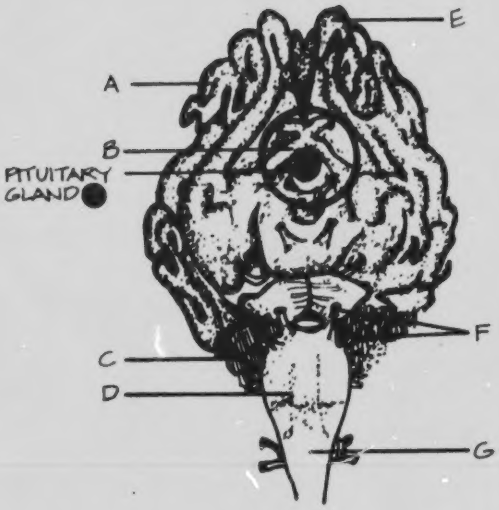


FIGURE 5: Base of a sheep brain.

The nerves go to and come from all parts of the head, including the skin, muscles and mouth. Some nerves carry information away from the brain, while other nerves carry it to the brain. Still other nerves carry information going in both directions. Such nerves contain some axons that carry information to the brain and other axons that carry it away.

19. Label the following diagram of the ventral surface of a sheep brain by writing the letters A through H on a separate sheet of paper and writing the name of the part next to each letter. (You may need to review the procedure.)

20. Match each disease process in the left column with the effect it would be most likely to produce.

Disease Process	Effect
A. Severe atherosclerosis of an artery in the middle of the left hemisphere of the cerebrum.	a. vision disturbance
B. Tumor in the hypothalamus.	b. paralysis of the right side of body
C. Brain tumor near the optic chiasm pressing against the chiasm.	c. abnormal body temperature
D. Tumor of the pituitary gland, causing the pituitary to secrete excess hormones.	d. slowed respiration
E. Severe head injury causing excessive pressure on the medulla.	e. abnormal concentration of certain hormones in the blood
F. Severe atherosclerosis of an artery in the middle of the right hemisphere of the brain.	f. paralysis of the left side of the body

PART II: MICROSCOPIC OBSERVATION OF THE BRAIN

MATERIALS:

microscope	2 glass slides with cover slips
scalpel or single-edged razor blade	medicine dropper

PROCEDURE:

1. Cut as thin a cross-sectional slice of the spinal cord as possible. (If the cord is missing, cut a slice of brain stem.) Place it on a slide, add a drop of water and add a cover slip. Using the 10X objective of the microscope, look for long strands near the edge of the specimen. These are the axons of nerve cells.

2. Make a scraping of the end of the spinal cord (or the end of the brain stem if the spinal cord is missing). Place the tissue on a slide, add a drop of water and a cover slip. Using the 10X objective, look for long strands and for small round masses. The former are axons; the latter are blood cells and cell bodies of nerve cells (See Figure 2). In nerve cells, the cell bodies are connected to the axons. When you make a scraping, the cell bodies break off from the axons.

DISCUSSION QUESTIONS:

1. Consider the number of axons in a small clump of nerve tissue. Assume that the tissue you observed is typical of the entrie nervous system. Based on your limited observations, would you estimate the number of nerve cells in the brain to be a hundred, a thousand, many thousands, or still more?

2. What advantage might there be to the peculiar shape of nerve cells?

LABORATORY ACTIVITY 2: OBSERVING ELECTRICAL IMPULSES IN NITELLA

INTRODUCTION:

In this activity you will observe the movement of electrical impulses in a plant called Nitella. Nitella, like all other plants, lacks neurons. But the impulses in a Nitella cell are similar to the nerve impulses in the neurons of animals. The set-up you will use (Figure 1) is similar to the one used in electrocardiography.

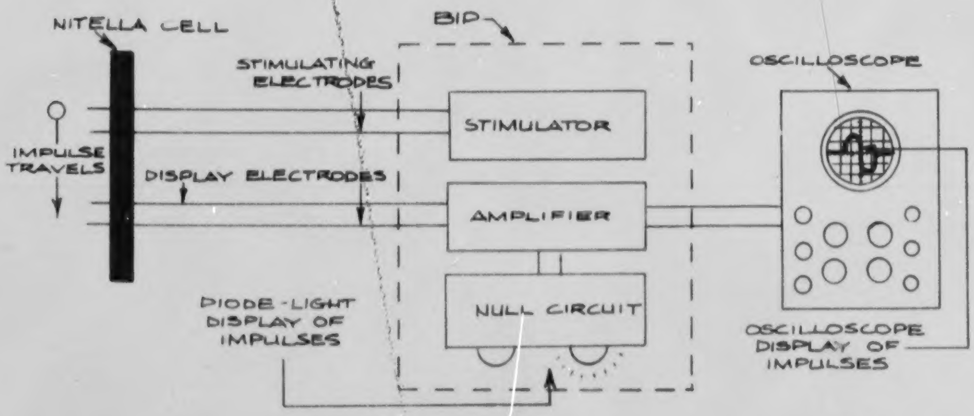

NITELLA CELL
BIP
STIMULATING ELECTRODES
OSCILLOSCOPE
IMPULSE TRAVELS
STIMULATOR
DISPLAY ELECTRODES
AMPLIFIER
NULL CIRCUIT
DIODE-LIGHT DISPLAY OF IMPULSES
OSCILLOSCOPE DISPLAY OF IMPULSES

FIGURE 1: Schematic diagram of experimental set-up.

Impulses could be demonstrated in neurons, but Nitella is better for this purpose because impulses move hundreds of times slower in the plant than in animal neurons. Thus what you will observe is like a slow-motion version of what happens in a nerve cell. Nitella is thus a useful model for studying nerve action.

It is possible to produce an electrical impulse in a Nitella cell by stimulating one end of the cell with a brief electrical current. The impulse that results from the stimulation travels down to the other end of the cell, where the display electrodes pick it up. The impulse may then be amplified and converted to a visual display on the oscilloscope or on the BIP diode lights (Figure 1).

The impulse can be picked up by electrodes because it involves a change in electrical charges in the environment of the cell. When the cell is not conducting an impulse, there is a higher concentration of positive ions in the fluid outside the cell than in the fluid inside. This net positive charge on the outside of the cell is shown in Figure 2A. But when an impulse sweeps along a cell, the positive ions surrounding the cell rush into the cell. Thus, as the impulse passes, the outside of the cell becomes temporarily more negative than it was before.

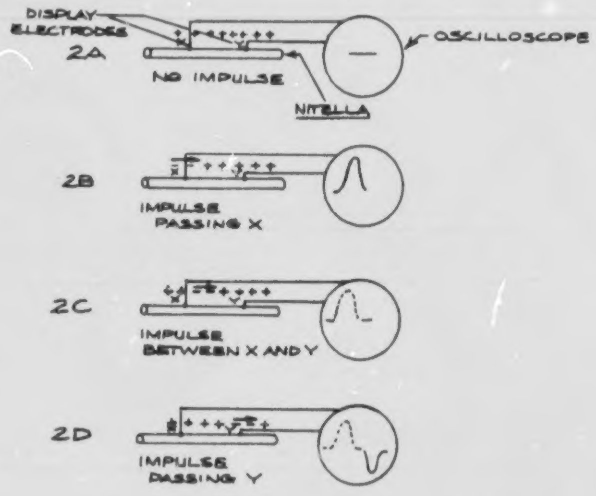


FIGURE 2: Charge differences displayed during an impulse.

Consider the Nitella cell shown in Figure 2. Two display electrodes contact the outside of the cell at points X and Y. When there is no impulse in the cell, there is a positive charge at both points X and Y (Figure 2A). Then when an impulse reaches point X, the outside of the cell is negatively charged at point X, but still positively charged at point Y; the display electrodes detect the difference in charge (Figure 2B). Next, the impulse moves on toward point Y, and the cell "recovers" at point X as positive ions diffuse to the outside; before the impulse reaches point Y, there is again a positive charge at both points X and Y (Figure 2C). Finally, as the impulse reaches point Y, the outside of the cell becomes negatively charged at point Y, while remaining positively charged at point X; again, the display electrodes detect the difference in charge (Figure 2D).

The difference in charge detected by the two electrodes can be displayed by the oscilloscope. The patterns produced by the oscilloscope are shown in Figure 2. As the impulse passes the electrode at X, the oscilloscope shows a pattern like a hill. When the impulse passes between X and Y, the oscilloscope shows no deflection. And when the impulse passes Y, a valley-like pattern appears on the oscilloscope. (The oscilloscope could also have been wired to show first a valley and then a hill.) The solid lines in the oscilloscope in Figure 2 show the pattern produced on the oscilloscope at each step. The dotted lines show the previous pattern.

You can also display the passing of an impulse by using the diode lights of the

BIP. However, the diode light will blink on only when the "hill" occurs on the oscilloscope; the "valley" will not be shown by the diode light.

MATERIALS:

- *Nitella*
- Petri dish
- Petri dish bottom, lid, or watch glass
- cardboard strip
- 2 toothpicks
- medicine dropper
- cellophane tape
- masking tape
- thumbtack
- ruler
- scissors, scalpel or single-edged razor blade
- nichrome wire, 22 gauge
- 2 electrodes with shielded cables (thick wires with plugs)
- 1 BIP wire, 60 cm in length
- 4 BIP wires, 30 cm in length
- 4 alligator clips
- 18,000-ohm resistor with two leads
- BIP
- small screwdriver
- wire cutter-strippers

PROCEDURE:

An efficient way to proceed is to distribute the tasks as follows. While one student makes the electrode stand (Steps 1 to 7), another may set up the BIP (Steps 8 to 10) and a third student may prepare the *Nitella* (Steps 11 and 12).

1. In the experimental set-up, the *Nitella* will be placed on four electrodes (Figure 3). Note that the four electrodes rest in an electrode stand. To make the electrode stand, draw a long rectangle on a strip of cardboard as shown by the heavy black lines in Figure 4 shown on the following page. The dimensions are 200 mm x 12 mm. Cut out the rectangle. Draw a long line on it as shown in Figure 4. Note: this line must be parallel to the upper surface or the electrodes will not be aligned correctly.

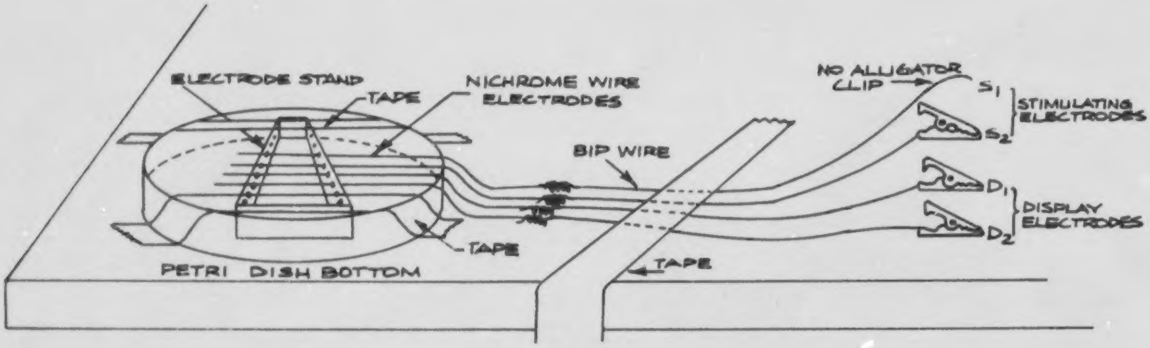


FIGURE 3: Electrode stand set-up. S_1 and S_2 are stimulating electrodes, D_1 and D_2 are displaying electrodes. BIP wires are drawn shorter than they really are.

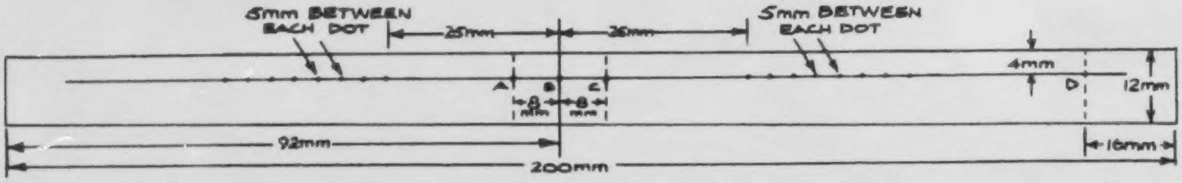


FIGURE 4: Preparing the electrode stand.

2. Draw lines A, B and C as indicated in Figure 4. Make two series of 8 dots 5 mm apart, noting that each series of dots begins 25 mm from line B. Draw line D, 16 mm from the right edge.

3. Cover the cardboard strip completely with cellophane tape. This helps to waterproof the cardboard. Then use a thumbtack to poke a hole at each of the dots. Fold the cardboard along lines A, C and D; and fasten the two ends together with tape (Figure 5).

4. Cut four pieces of nichrome wire, each about 12 cm long. These wires will serve as electrodes.

5. Obtain the following: two shielded electrodes (from a set of ECG electrodes), one piece of BIP wire 60 cm in length, four pieces of BIP wire 30 cm in length, and 4 alligator clips. Strip about 2 cm of insulation from each end of the 30-cm BIP wires and attach three of these wires to alligator clips.

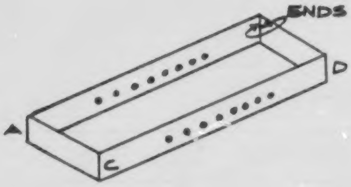


FIGURE 5: The electrode stand.

6. Twist together the nichrome wires and the bare ends of the three BIP wires with alligator clips attached (See Figure 3). These are important connections, so make 5 or more twists for each. In the same way, twist together a piece of nichrome with the 30 cm length of BIP wire without an alligator clip.

7. To set up the electrode stand as in Figure 3, obtain a Petri dish. Insert the nichrome electrodes through four adjoining holes in the electrode stand. Be sure to put the electrode without the alligator clip at one end, as in Figure 3.

Tape the BIP wires to the table with masking tape to keep them steady. Put the electrode stand in the Petri dish bottom and bend the wires over the rim of the Petri dish slightly to keep them stable. Then securely tape the ends of the electrode stand along with the Petri dish to the table, to keep the whole set-up steady. (See Figure 3.)

8. Program the BIP to stimulate the *Nitella* as shown in Figure 6 on the following page. Also make the connections shown for using an oscilloscope, if one is available. (Ignore the wire labeled "bare, taped down" until you get to Step 9. Ignore "electrode S," until you get to Step 10.)

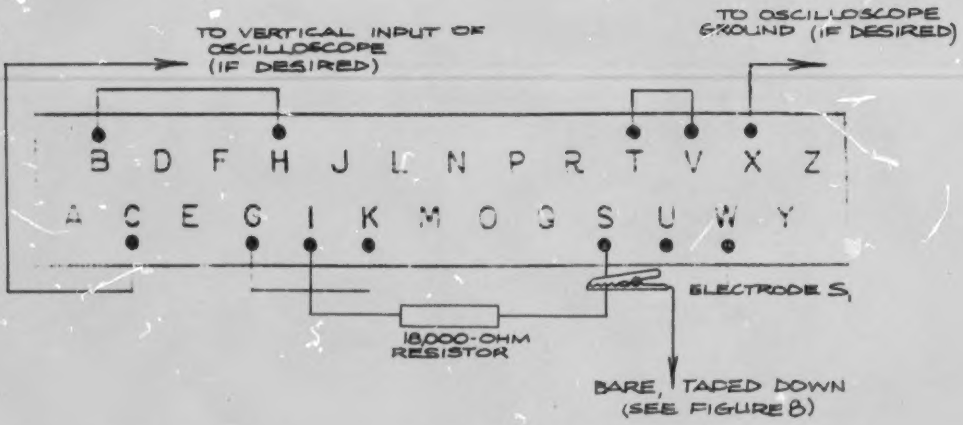

TO VERTICAL INPUT OF OSCILLOSCOPE (IF DESIRED)
TO OSCILLOSCOPE GROUND (IF DESIRED)
B D F H J L N P R T V X Z
A C E G I K M O Q S U W Y
ELECTRODE S_1
18,000-OHM RESISTOR
BARE, TAPED DOWN (SEE FIGURE 8)

FIGURE 6: Programming the BIP to stimulate Nitella.

9. Make the wire labelled "bare, taped down" in Figure 6 by taking the 60-cm length of BIP wire and stripping about 2 cm from one end and 8 cm from the other end. Attach the short stripped end to an alligator clip. Connect the alligator clip to the wire coming from S on the BIP (Figure 6). Tape the other end to the table in front of the BIP, as shown in Figure 8 on the following page. Don't tape it to a metal surface. This wire and "electrode S," will be used to deliver a brief electric current to the plant.

10. If Step 1 through 9 have been completed, the electrode stand is ready to be connected to the BIP. First, use a screwdriver to turn the gain control (the extreme right slotted control on the front of the BIP) all the way counterclockwise. Next, insert the plugs of the two electrodes with shielded cables (thick wires with plugs) into the two input jacks located at the lower-right corner of the front of the BIP. Connect the other end of each of these electrodes to the alligator clip on one of the two display electrodes (D_1 and D_2) from the electrode stand. Connect the electrode from the right input jack to D_1 and the electrode from the left input jack to D_2 (Figure 3). Connect electrode S_1 from the electrode stand to W on the BIP (Figure 6). Plug in the BIP. Make sure none of the metal parts of the set-up is touching a metal surface, because this will affect the results.

11. Your next task will be to prepare Nitella cells for testing. Note: The Nitella should not be touched by any metal surface. Use a toothpick to handle Nitella. Select a strip of Nitella that is uniformly green (or at least not splotchy). Transfer the strip of Nitella along with some of the fluid it is in to a Petri dish bottom or lid or a watchglass.

12. Nitella cells are connected by small bumps known as nodes (Figure 7). The region between two nodes is one cell. Select for study a cell at least 25 mm in length. Trim away the cells on each side of it by cutting about 1 mm on either side of the selected cell's nodes (Figure 7).

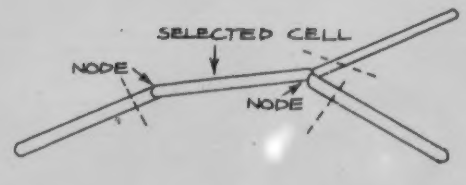


FIGURE 7: Preparing Nitella. Dashed lines show where to cut.

Use scissors to cut. It is all right to use metal scissors to do this, as long as you avoid touching the selected cell itself with the scissors. Do the cutting with the cell submerged in its solution to avoid damaging the cell. Also do not bend the cell, for this too can cause damage.

Prepare three or four specimens in this manner and keep them immersed in their solution in the Petri dish or watch glass until use.

13. Place a prepared Nitella cell onto the four nichrome electrodes so that it lies across them within the electrode stand. Make sure the cell touches all four electrodes; move it around if necessary. (For very large cells you may have to place the two sets of electrodes farther apart: move the pair of stimulating electrodes farther from the pair of recording electrodes.)

14. Keep the cell wet by adding a few drops of water from the solution every 5 minutes or so. This maintains good electrical contact between the cell and the electrodes and keeps the cell healthy. Without pressing down on the wires, place the Petri dish top over the set-up.

15. Adjust the mA dial to the null point, then move the dial 20 mA units higher. The left diode light should remain on.

16. To proceed, it will be necessary to deliver a very brief burst of current--ideally about .005 second long--to the cell. Read the rest of this step through before proceeding. (The Nitella cell should have two minutes to rest in the electrode stand before you deliver the burst of current.)

To deliver so short a pulse, you will use the alligator clip of electrode S_2 (Figure 3) and quickly sweep it once across the bare wire taped to the table (Figure 8). During the time that the alligator clip touches the wire, current will pass from the BIP through one stimulating electrode, through the plant, through the other stimulating electrode and back to the BIP. Begin with the alligator clip 15 to 20 cm or more away from the bare wire to give your hand a long "runway" on which to accelerate. Sweep the alligator clip across the bare wire as fast as you can or the burst of current will be too long. Run the alligator clip on the tabletop and across the wire.

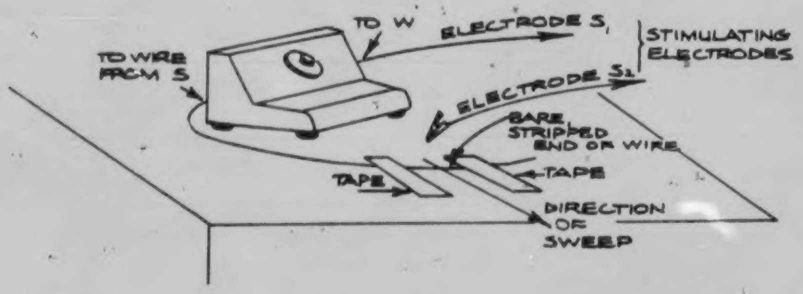


FIGURE 8: Delivering the burst of current.

17. Now one person delivers the pulse while one or more others watch the diode lights. Deliver the short pulse. The right diode light will blink briefly during the pulse. If the plant responds, then a few seconds later the right diode light will go on as the impulse passes the first display electrode. This corresponds to Figure 2B. With this set-up, you can't use the left diode light to tell when the impulse passes the second electrode, for this light goes on not only when the impulse passes the second electrode but also when the impulse is passing anywhere on the plant other than the first electrode. It is even on when there is no impulse."

Wait two minutes to let the cell recover, then stimulate it again. If the plant does not respond to the first and second stimulations, check all connections and the programming. If there is no error, try a different specimen. Always wait at least two minutes between tests. Also wait for two minutes after first putting a specimen on the electrode stand.

18. Once you get the set-up to work, you may run some of the following tests.

a. Does Nitella fire an impulse in response to other stimuli such as touch, light or a puff of air?

b. If you set the two display electrodes (D_1 and D_2) farther from each other, what is the effect on the display of the response? What is the effect if you set the display electrodes farther from the stimulating electrodes?

c. To display the impulse passing the second electrode using the BIP, reverse the input jacks at the BIP. Then a diode light will blink when the impulse passes the second electrode. What is the pattern of the diode display in this case?

d. What happens to the display of the impulse if you cut the Nitella between the two display electrodes while it is in the electrode stand set-up? Repeat this test (after two minutes) with the input jacks reversed.

DISCUSSION QUESTIONS:

1. Why does the right diode light go on after the plant is stimulated?

2. What is the main advantage of studying impulses in Nitella rather than in a neuron?

3. In this activity a burst of electric current is used to stimulate the plant. What are some of the things that normally stimulate the neurons in the human body to respond with nerve impulses?

LABORATORY ACTIVITY 3: MONITORING BRAIN WAVES--ELECTROENCEPHALOGRAPHY

INTRODUCTION:

An electroencephalogram (EEG) is a tracing of the varying electrical voltages that are continuously moving through the cortex of the brain. This activity starts with a demonstration during which you will have a chance to observe brain waves. Brain waves are picked up from the scalp of a subject, amplified by the BIP and viewed on an oscilloscope screen.

Following this demonstration, individual groups will study the electrical activity of the brain using the diode lights of the BIP. The principle employed is similar to that used for displaying ECG waves in Unit III. The mA dial of the BIP is adjusted so that the current coming from the brain fluctuates above and below a "base line" determined by the mA setting (Figure 1). When the mA dial is properly set the current from the brain is greater than the mA setting about half the time and less than the setting the other half of the time. When the current is greater than the mA setting, one diode lights up, and when it is less than the mA setting, the other diode lights up. So each diode light is lit about half of the time, if the setting is correct.

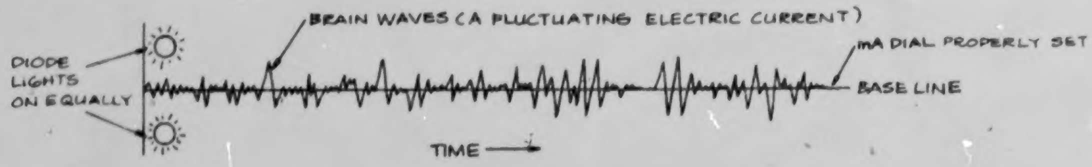

BRAIN WAVES (A FLUCTUATING ELECTRIC CURRENT)
mA DIAL PROPERLY SET
DIODE LIGHTS ON EQUALLY
BASE LINE
TIME →

FIGURE 1: mA setting for monitoring the general brain-wave pattern.

With the mA dial adjusted as described above, you will be monitoring a variety of brain waves picked up by the electrodes. In an alert person, with the eyes open, these waves are primarily beta waves. By making a small adjustment with the mA dial it is possible to detect alpha-wave activity. This is done by increasing the mA setting slightly so that only waves of greater height (i.e., alpha waves) trigger the second diode to light (Figure 2).

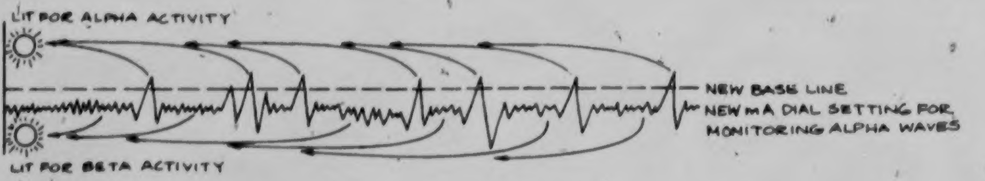

LIT FOR ALPHA ACTIVITY
NEW BASE LINE
NEW mA DIAL SETTING FOR MONITORING ALPHA WAVES
LIT FOR BETA ACTIVITY

FIGURE 2: mA setting for monitoring alpha activity.

Why does the increase in mA setting result in monitoring alpha waves and not beta waves? Since the height of the beta waves is smaller than that of alpha waves, the current coming from the brain during beta activity is always less than the "base line" and only one diode lights up (Figure 2). Then each time an alpha wave comes along the current "peaks" over the "base line" and the other diode lights up.

MATERIALS:

BIP

2 electrodes with shielded cable (thick wires with plugs)

electrode with unshielded cable (thin wire)

18,000-ohm resistor with two leads

programming wire

2 elastic bandages (or strips of 2" gauze, each 3 ft long)

roll of masking tape or fasteners
  for elastic bandages

electrode paste

acetone

cotton or cotton balls

light shield (cloth, etc.)

PROCEDURE:

1. Program the BIP as shown in Figure 3. (Additional connections are shown for use of an oscilloscope, in case one is available.)

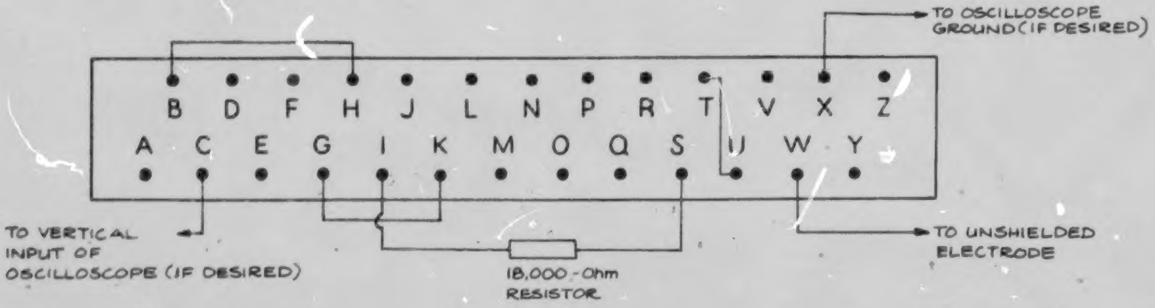
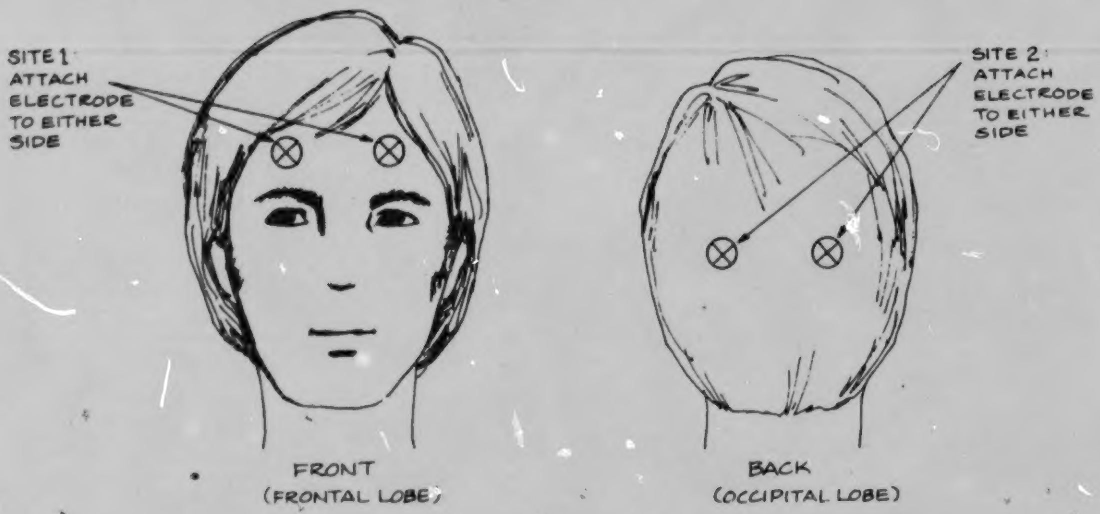

TO OSCILLOSCOPE GROUND (IF DESIRED)
B D F H J L N P R T V X Z
A C E G I K M O Q S U W Y
TO VERTICAL INPUT OF OSCILLOSCOPE (IF DESIRED)
18,000-Ohm RESISTOR
TO UNSHIELDED ELECTRODE

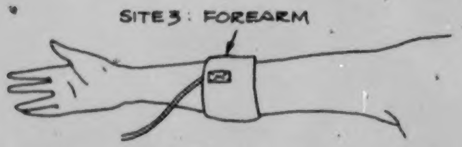
FIGURE 3: BIP programming for monitoring brain waves.

2. Connect a student to the BIP. (Don't plug in the BIP until Step 6.) First, have the student sit on a chair. Then, using acetone (or soap and water), thoroughly clean an area on the parts of the body numbered 1, 2 and 3 in Figure 4. The cleaned areas should be somewhat larger than the size of the ECG electrodes. This is done to remove skin oils which could prevent good electrical contact. This is very important. Poor electrical contact between the electrodes and the body can be a cause of failure of this activity.

3. Smear electrode paste on the two electrodes attached to shielded cables. Bandage these electrodes to the body sites 1 and 2 in Figure 4. Note that the electrode to body site 2 is to be bandaged to the left or right of the center line on the back of the scalp. Be sure the electrodes do not slip from the cleaned area during bandaging. On site 2, try to get as good skin contact as possible by moving the hair to either side. Smear electrode paste on the electrode attached to the unshielded cable and bandage it to body site 3 on the right forearm.



A: Shielded electrodes.



B: Unshielded electrode.

FIGURE 4: Electrode placement.

4. Note the two input jacks in the bottom right-hand corner of the front panel of the BIP. Insert one of the electrode leads from the scalp into each of these jacks.

5. Insert the electrode lead from the arm (the one with the unshielded cable) into the W terminal on the BIP.

6. Plug in the BIP and adjust the mA dial so that both diode lights are on about the same amount of time.

7. In order to detect alpha waves, reset the mA dial as follows. Increase the mA setting slowly until one diode is lit all the time. Then have the subject blink his or her eyes. Blinking the eyes produces a wave of electrical activity of approximately the same height as alpha waves. The object is to set the mA dial so that one of the diodes is lit most of the time and the other diode lights only when the subject's eyes are blinked.

8. Have the subject relax as much as possible. Covering the eyes to block out light is also helpful. The jaw should be relaxed, with no blinking of the eyes or swallowing, because these movements will light the "alpha" diode.

It may be difficult to demonstrate a high proportion of alpha waves, especially in a classroom setting. Be prepared to allow 5 to 10 minutes for the subject to relax. When the subject is producing mostly alpha waves, the second diode should be lit most of the time. Keep in mind that occasional alpha waves are produced even in an individual who is not trying to relax.

9. If your subject is demonstrating a predominance of alpha activity, ask the subject to perform a calculation such as addition of two or three numbers. Record the effect of calculating on the EEG.

10. Switch roles, and repeat Steps 2 through 9 with another subject. (NOTE: The correct mA settings may vary slightly from one person to another because the height of individuals' brain wave patterns will vary.)

DISCUSSION QUESTIONS:

1. Did the proportion of alpha to beta activity produced vary with time in the individuals in your group? If so, did it increase or decrease?

2. What techniques, if any, did subjects in your group develop to aid them in producing alpha activity?

3. If your subject performed Step 9, how did the calculations affect the brain wave patterns?

LABORATORY ACTIVITY 4: BIOFEEDBACK

GENERAL INTRODUCTION:

In Section 4, we discussed some of the physiological processes that people have learned to control by means of biofeedback training. In this activity you will attempt to control certain physiological variables in much the same manner as a person in a biofeedback training program.

Three specific variables have been chosen: alpha waves, skin temperature and pulse rate. You have already had experience with each of the measurement techniques to be used. For example, to monitor alpha activity, you will use the apparatus used in the EEG activity. Variations in skin temperature will be measured by means of a thermistor attached to your index finger. Heart rate will be monitored by the technique used in the Circulatory System Unit. Each of these three measurements will be made at different stations in the classroom and you will have the opportunity to try each. The order in which you move from station to station is not important. It will be convenient to work in pairs in this activity so that while one of you attempts to generate a specific response, the other can observe and tell you when you are successful. Then you can switch roles.

STATION I: INCREASING ALPHA-WAVE PRODUCTION

INTRODUCTION:

At this station you will find a BIP, already programmed for EEG, and attached to an oscilloscope. The arrangement is the same as that used in the preceding activity with the exception that a filter has been added to the circuit to screen out most beta waves.

In this activity, an observer must tell you when you are producing alpha waves. But each time the observer communicates with you, it will be distracting. Such distractions are likely to inhibit production of alpha waves. So choose a method of communication that will bother you as little as possible. Exactly how you do this is up to you. You might try having the observer touch you lightly whenever alpha waves are on the oscilloscope. Or perhaps you could have the observer simply say "now" in a soft voice, each time alpha waves appear.

MATERIALS:

2 electrodes with shielded leads (thick cables)

electrode with unshielded lead

18,000-ohm resistor, with two leads attached

BIP

2 elastic bandages (1 meter each), with 2 clips

programming wire

electrode paste

acetone

absorbent cotton

light shield (cloth, etc.)

clock or watch with second hand

PROCEDURE:

1. Connect the three electrodes to a subject as you did in Laboratory Activity 3. Then ask the instructor to adjust the oscilloscope.

2. Have the subject blink his or her eyes a few times. The waveform that results will give a rough idea of the height of an alpha wave. However, in general, alpha waves are a bit smaller than those resulting from eye blinking.

3. Have the subject close his or her eyes. (It may help to cover the subject's eyes to keep out the light.) Instruct the subject to begin to attempt to increase alpha-wave production. Each time alpha waves appear, give the subject the signal that has been decided on.

(NOTE: It may take some time for the subject to relax. Plan to allow at least 5 to 10 minutes for this portion of the activity. During this time try not to do anything that would distract the subject, i.e., no talking, moving around, fiddling with things, etc.)

4. You may wish to count the number of times you observe alpha waves being produced during three five-minute periods to see whether the subject is learning how to generate the alpha waves. To do this, tell the subject when to start, note the time and then note every time alpha waves appear. At the end of the activity you can tabulate the results.

5. Switch roles and repeat the entire procedure.

STATION II: ALTERING SKIN TEMPERATURE

INTRODUCTION:

One biofeedback method commonly used to help people who suffer from migraine headaches is to train them to increase the temperature in their hands or fingers. In this portion of the activity you will attempt to perform this feat. A thermistor attached to a finger will monitor skin temperature of that finger. The observer will be taking your skin temperature every minute for 5 to 10 minutes and will notify you of any changes that occur.

If you do not have any ideas about how you might try to raise the temperature in your finger, you may memorize and think about some of the following phrases. (These phrases have been used successfully by biofeedback specialists to raise the skin temperature of subjects.)

1. I feel quite quiet.
2. I am becoming more and more relaxed.
3. My whole body feels quiet, heavy and relaxed.
4. My hands and fingers are heavy.
5. My fingers are warm.
6. Warmth is flowing into my fingers. They are warm.
7. My fingers are warm--relaxed and warm.

MATERIALS:

BIP with thermistor component

cotton

clock or watch with second hand

tape

PROCEDURE:

1. Have the subject relax in the chair provided at the station.

2. Place the thermistor flat against the tip of the right index finger as in the diagram. Cover it with a small wad of cotton and secure it with a piece of tape wound around the finger. (NOTE: Do not wind the tape too tightly or you will impede blood flow into the finger.)

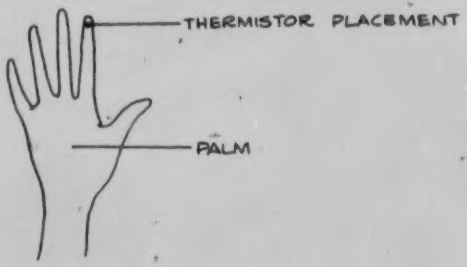


FIGURE 2: Thermistor placement on right index finger.

3. Wait one minute for the temperature of the thermistor to equilibrate. Then turn the mA dial on the BIP until the diode lights null. Inform the subject of the dial reading.

4. Instruct the subject to attempt to raise the temperature of the finger. (Remember to be quiet and not distract the subject during this time.)

5. Readjust the mA dial to the null position. Every minute for 5 to 10 minutes, determine the temperature of the subject's right index finger. (Take careful readings because very slight temperature increases may be the result.) Inform the subject of the value and whether the readings are increasing. Record the value.

(Note: in experiments of this type, the initial response is often a decrease in temperature.)

6. Switch roles and repeat the procedure for the second subject.

STATION III: INCREASING HEART RATE

INTRODUCTION:

Biofeedback involving the regulation of a person's heart rate has been used with people who suffer from certain types of heart disease. In clinical situations, a decrease of heart rate is often desired. Some subjects merely give themselves the suggestion that they are becoming more and more relaxed and then "will" their heart rate to decrease. Other people prefer to use visual images of relaxing scenes.

At this station you will find a BIP attached to a photocell. This set-up is the same as the one you used to measure heart rate (arteriolar pulse rate) in Unit III. One student will serve as the subject and will attempt to increase his or her heart rate. (It is easier to increase the heart rate than to decrease it.) The observer will make 15-second pulse counts about every half minute and inform the subject of the heart rate.

MATERIALS:

clock or watch with second hand
BIP
light source
photocell and associated circuitry
ring stand and 2 clamps

PROCEDURE:

1. At this station there is a lamp and photocell mounted on a ring stand. The photocell is connected to a BIP. Plug in the BIP and have the subject place the end of his or her middle finger on the top of the photocell so that it completely covers the cell.

2. Adjust the lamp so that it touches the top of the subject's finger.

3. Use the mA dial to null the diode lights on the BIP. The BIP lights monitor the change in blood flow in the finger that occurs with each heartbeat. The subject may have to press harder or lighter on the photocell until the diode lights begin to blink. (The mA dial may need to be adjusted to give a more sensitive indication.)

4. Have the subject rest his or her arm on the table, so that it is relaxed and does not move.

5. Determine the subject's pulse by counting the blinking of the BIP diode lights for 15 seconds. This should not be hard for you to do if you hold a watch with a second hand next to the diode lights, so that you can see both things at once. Practice doing this a few times until you feel confident with the technique.

6. Instruct the subject to begin attempting to increase the heart rate. Roughly every 30 seconds take the subject's heart rate by counting the blinks of

the diode lights. Multiply that number by four. Inform the subject of his or her heart rate and whether it is increasing. Record the data.

7. Switch roles and repeat the procedure.

DISCUSSION QUESTIONS:

1. Were you able to increase production of alpha waves? If so, what conditions or factors were helpful? What conditions inhibited production of alpha waves?

2. Do you know of any students in your class who meditate regularly? If so, were they more or less successful in producing alpha waves than non-meditators?

3. Were you able to increase the skin temperature of your finger? How might this ability be useful in medicine?

4. Were you able to increase your heart rate?

5. Speculate about what other body functions might be suitable for biofeeback training.

LABORATORY ACTIVITY 5: EXPLORING REFLEXES

INTRODUCTION:

The reflexes of the body are useful for checking out many portions of the nervous system. If the neurons that make up a reflex arc are not functioning properly, the normal reflex may be absent or at least reduced. And if brain neurons that inhibit the reflex are not functioning properly, the reflex may be stronger than normal.

A normal response may vary quite a lot from one person to the next. So the important question, usually, is whether both halves of the patient behave alike. A strong knee jerk may not be significant if both legs show a strong reflex. But if one is weak, something's probably wrong.

In this activity you will examine several different reflexes. There are many more that may be used to test other parts of the body, but these are among the most commonly tested.

It would be a good idea to compare reflexes on both sides of your subject's body to see whether they are equally vigorous. But don't be alarmed if the responses differ a little--a reflex action is very sensitive to (1) getting the subject to relax completely, (2) locating the exact point to stimulate and (3) applying the right amount of force.

In all the tests, you and the other students in your team should take turns as tester and subject. The activity is designed to be performed in any order. In other words, it is not necessary to do Part I before Part II and so on.

MATERIALS:

reflex hammer

clear plastic sheet

pencil with eraser tip

pen-light

PROCEDURE:

PART I: Quadriceps Reflex ("Knee Jerk")

1. This reflex is probably most easily produced if the subject sits on a desk

or table with both legs hanging loosely. Alternatively, have the subject sit with legs crossed at the knee so that the leg to be tested hangs free. It may be helpful here to have the male subjects roll up their pants above the knee.

2. The tendon that attaches the quadriceps muscle to the lower leg bone runs under the knee cap. Striking that tendon with a reflex hammer stretches the muscle, which brings on the "knee jerk" reflex. Test for the knee jerk reflex by giving your subject a sharp tap just below the knee cap. (Do not tap too hard.)

3. You may wish to try an alternative technique. Place your finger on the tendon and tap your finger. That technique demands less accuracy than the hammer blow (and also ensures that the tester will do the suffering if he is heavy-handed).

4. Sometimes a reflex is inhibited by the brain. Your subject may be a little tense, causing the quadriceps muscle to be partially contracted. The subject may not be sufficiently relaxed to give the normal response. Neurologists cause their subjects to relax one muscle by having their subjects concentrate on other muscles. For example, have your subject hook fingers together and pull. While your subject is doing this, repeat Steps 1 to 3.

5. Record your observations.

PART II: Hamstring Muscle Reflex ("Ankle Jerk")

1. The Achilles (pronounced uh-KILL-eez) tendon is the elastic tissue that attaches the hamstring muscle to the heel bone. A reflex in the hamstring muscle can be produced by tapping the tendon.

2. Have the subject remove his shoes and sit on a table with his feet hanging free. Alternatively, he may stand on one foot with the other knee bent, the shin supported by a chair, and the foot hanging free. Or the subject may kneel on the chair. A tap on the Achilles tendon should produce a jerking of the foot caused by contraction of the hamstring muscle. The place to tap is about 1 to 2 cm above the ankle bone and in the back of the leg. See Figure 1

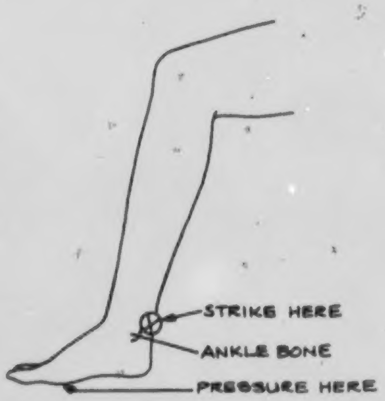


FIGURE 1: Where to tap to obtain the hamstring muscle reflex.

3. The reflex may be reinforced by putting a hand under the ball of the subject's foot and having his press it lightly, putting a slight tension on his hamstring muscle.

4. Record your observations.

PART III: Biceps Reflex

1. Have the subject sit comfortably with his arm resting on a table top, palm up, and with sleeves rolled up to expose the biceps muscle.

2. Locate the tendon that connects the biceps muscle to the bones in the forearm. To find the correct area, press your fingers into the crease of the elbow and

have the subject contract the biceps muscle. The string-like tendon can be easily felt and may also be visible.

3. Tap sharply at the point indicated in Figure 2. It will be important for the subject's arm muscles to be relaxed.

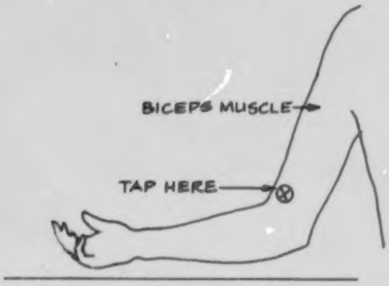


FIGURE 2: Positioning a subject to check for the biceps reflex.

4. It may be helpful to press the tendon with two fingers and then strike your fingers.

5. Record your observations.

PART IV: Triceps Reflex

1. Position the subject as in Part III, except with the elbow extended 2 to 5 cm beyond the edge of the table. The subject's palm may be up or down.

2. Find the tendon connecting the triceps muscle to the bone, just above the elbow. The triceps muscle runs down the back of the upper arm. The correct region may be most easily found if the subject contracts the biceps muscle voluntarily. The region on the opposite side of the arm that stiffens is the triceps muscle.

3. Have the subject relax the triceps muscle. Then tap the subject about three cm above the elbow--at a point on the arm opposite to the region tapped in Part III.

4. Record your observations.

PART V: Brachioradialis Reflex

1. Position the subject as in Part III, except with his palm down and with his hand dangling off the edge of the table.

2. Tap the muscle that runs diagonally across the forearm (Figure 3 on the following page). This is the brachioradialis (pronounced BRAY-key-o-RAY-dee-A-liss) muscle.

3. Record your observations.

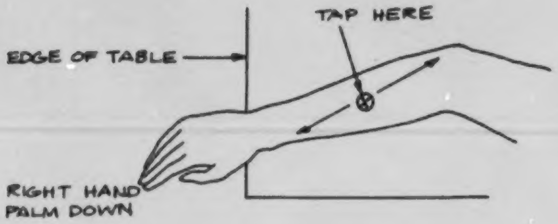


FIGURE 3: Positioning a subject to check for the brachioradialis reflex.

PART VI: Pupil Reflexes

1. When a light is shone on an eye, the pupil of that eye responds in a characteristic way. The pupil of the other eye is also affected. The reflex may be produced by shining a small flashlight at each eye in turn.

2. With the subject looking at a distant object (a spot on the opposite wall, for example), shine a light into one eye. (Don't point the flashlight directly into the eye. Rather shine the light from slightly below the eye.) Observe the change in pupil size. Observe also the change in the unlighted pupil. Test both eyes. (Since a person's pupils may enlarge when he is startled, turn the light on first and approach the eye gradually.) The test works best in subdued light. Record your observations. Note particularly the diameter of the pupil before and after the light is shone on it.

3. It is possible to test for other reflex actions involving the eye. With the subject initially looking at a distant object, have the subject change focus to a nearby one (a pencil in your hand, for example). Observe any change in pupil size.

4. Record your observations.

PART VII: Blink Reflex

1. Have the subject place the clear plastic sheet directly before his face, touching his nose and/or forehead.

2. Tap the sheet with the eraser end of a pencil directly in front of one eye. Observe whether blinking occurs in one eye, both, or neither. Test each eye.

3. Repeat taps in front of one eye at approxomately one-second intervals. Does the blinking reflex persist? If not, how many taps were made before it stopped?

4. Record your observations.

DISCUSSION QUESTIONS:

1. Which reflexes were easiest and which were hardest to demonstrate?

2. What conditions increased the reflex actions? Decreased the reflex actions?

3. You probably found that you could increase the quadriceps reflex action by having the subject clasp fingers and pull the arms in opposite directions. What does the brain have to do with this increase in response?

4. Uneven responses in reflex tests on opposite sides of the body may indicate a disorder of the nervous system. You may have obtained different results on opposite sides of your subject. Yet your subject could be perfectly normal. Explain.

LABORATORY ACTIVITY 6: ANALYSIS OF CEREBROSPINAL FLUID

INTRODUCTION:

Analysis of the cerebrospinal fluid (CSF) is an important method in the diagnosis of a variety of conditions that affect the central nervous system. In this activity you will analyze CSF for the presence of (1) red blood cells, (2) increased total protein concentration and (3) increased gamma globulin concentration. These tests are made routinely whenever a spinal fluid sample is taken. You will test four different simulated spinal fluids for these abnormalities.

The test for red blood cells uses a centrifuge to concentrate any red blood cells that may be in the sample, and a microscope for looking for the blood cells. In the test for high protein concentration, the protein is precipitated by adding sulfosalicylic acid solution to the sample. The resulting turbidity is measured with the BIP. Testing for high levels of gamma globulin involves precipitating the gamma globulin by mixing spinal fluid and ammonium sulfate solution. Other proteins (such as albumin) are not precipitated by this procedure. Note: it is possible to have a clinically high gamma globulin concentration in CSF and yet have a normal total protein concentration, since gamma globulin accounts for only a small percentage (∿10%) of the total protein in normal blood.

PART I: EXAMINATION FOR RED BLOOD CELLS

MATERIALS:

4 simulated cerebrospinal fluids (in containers labeled "A," "B," "C" and "D")
centrifuge
4 centrifuge tubes
Parafilm
two microscope slides with cover slips
4 medicine droppers
microscope
glass-marking pencil
test-tube rack

PROCEDURE:

1. Label four centrifuge tubes "A," "B," "C" and "D." (Since the number of centrifuges may be limited, you may have to share the centrifuges and centrifuge tubes with your classmates. If a centrifuge and centrifuge tubes are not available, do either Part II or Part III of the activity before beginning Part I.)

2. Fill each centrifuge tube about half full with the corresponding cerebrospinal fluid sample. Seal each tube with a small piece of Parafilm.

3. Place the tubes in the centrifuge. Make sure that the centrifuge is

balanced; each tube should be placed directly across from one of the other tubes (see Figure 1). An unbalanced centrifuge may result in broken tubes when the centrifuge is turned on. Close the cover of the centrifuge.

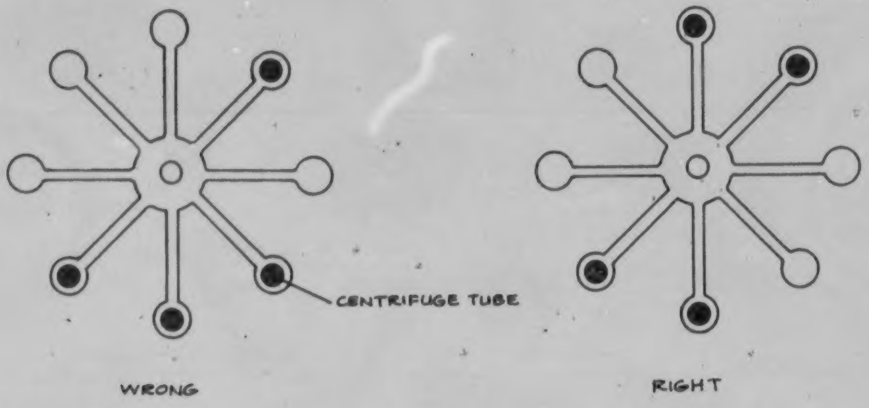


FIGURE 1: The right and wrong ways to load a centrifuge.

4. Switch on the centrifuge and let it run for 5 to 10 minutes at maximum speed. The centrifugation causes any red blood cells in the samples to settle to the bottom of the tubes.

5. After the samples have been centrifuged, gently remove the tubes from the centrifuge. Do not shake the tubes. Using a clean medicine dropper with each tube, carefully draw off and discard the upper portion of each sample. Do not discard the lower 0.5 ml or so. Once you have removed the upper portion, you may leave the medicine dropper in the tube until Step 7.

6. You will now need to examine the concentrated samples with a microscope in order to determine which samples, if any, contain red blood cells. Label two microscope slides as shown in Figure 2.

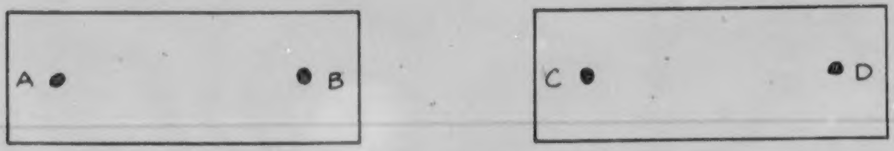


FIGURE 2: Labeled slides.

7. In the appropriate positions, place a small drop of each of the concentrated samples. Cover the drops with cover slips.

8. Examine the slides with the 10 X objective for the presence of red blood cells. Be sure that the microscope light is not too strong, because too much light

can make the cells hard to see. You may recall that the red blood cells look like small doughnut-like discs. If you don't find any red blood cells after examining a sample for several minutes, there probably aren't any.

9. Record your results.

10. Clean the centrifuge tubes and medicine droppers so that they may be used by other groups.

PART II: TEST FOR HIGH PROTEIN LEVELS

MATERIALS:

4 simulated cerebrospinal fluids (in containers labeled "A," "B," "C" and "D")
5 cuvets, 16 x 125 mm, Pyrex
5 pipets, 10-ml
Parafilm
BIP
colorimeter test well
test-tube rack
protein reagent (sulfosalicylic acid solution)

PROCEDURE:

1. Connect the colorimeter test well to the BIP. Also, connect H to L and T to U on the BIP programming panel. Plug in the BIP.

2. Label four cuvets "A," "B," "C" and "D."

3. Pipet 4.0 ± 0.1 ml of the four simulated cerebrospinal fluids into the corresponding cuvets. Use a different pipet for each sample.

4. Pipet 2.0 ± 0.1 ml of protein reagent into each cuvet, seal the cuvets with Parafilm and shake the cuvets gently. (Some turbidity should be noticeable in all four cuvets.) Let the cuvets stand for five minutes.

5. To standardize the BIP, first set the mA dial at 100. Then place a clean cuvet containing about 10 ml of water in the test well. Adjust the slotted control just below and to the left of the mA dial until the diode lights null. Remove the cuvet from the test well.

6. When five minutes are up, invert a sample to mix the precipitate thoroughly.

7. Determine the %T for the sample. Record the reading.

8. Repeat Steps 6 and 7 for each of the remaining samples. The protein concentration of a sample should be considered abnormally high if the %T is less than 60. (Such a reading corresponds to more than 45 mg protein per 100 ml.)

PART III: TEST FOR HIGH GAMMA GLOBULIN LEVELS

MATERIALS:

4 simulated cerebrospinal fluids (in containers labeled "A," "B," "C" and "D")
4 test tubes, 16 x 125 mm
pipet, 1-ml
4 pipets, 10-ml
gamma globulin reagent (ammonium sulfate solution)
Parafilm

PROCEDURE:

1. Clean four test tubes and relabel them (A,B,C,D) if necessary.

2. Pipet 1.0 ± 0.1 ml of gamma globulin reagent into each of the tubes.

3. To one tube, add 1.0 ± .1 ml of the spinal fluid to be tested, cover the tube with Parafilm and shake gently. Repeat for the other three samples. Use a different pipet for each sample.

4. Examine the tubes for turbidity (cloudiness). A sample containing high levels of gamma globulin should be slightly turbid. Record your results.

DISCUSSION QUESTIONS:

1. What brain diseases might correspond to each of the four cerebrospinal fluid samples tested?

2. If you did not find red blood cells in the cerebrospinal fluid of a patient, speculate on whether you could assume that the patient did not have a cerebral hemorrhage.

LABORATORY ACTIVITY 8: DISCOVERING VISUAL GAPS

INTRODUCTION:

Testing the visual field can often be important in diagnosing brain disease. Each of us has a normal gap or "blind spot" in the visual field of each eye. Unnatural gaps may point to diseases of the optic nerves, which carry visual information to the brain, or diseases of the portion of the brain that interprets that information. But they may also arise from causes that are outside the optic system itself. For example, a tumor that presses against an optic nerve may first become noticeable as a visual-field defect.

The normal visual gaps or blind spots are due to the structure of the retina, which is the part of the eye that receives visual stimuli. Located on the rear-inside surface of the eye, the retina is composed of special cells that respond to light and color. A small area on the surface of the retina called the "optic disk," has no light-sensing cells; this area is the connection point for the optic nerve, and accounts for the blind spot. In this activity you will map the location of the blind spots by the "tangent-screen" technique, which is commonly used in visual-field testing for brain disease.

MATERIALS:

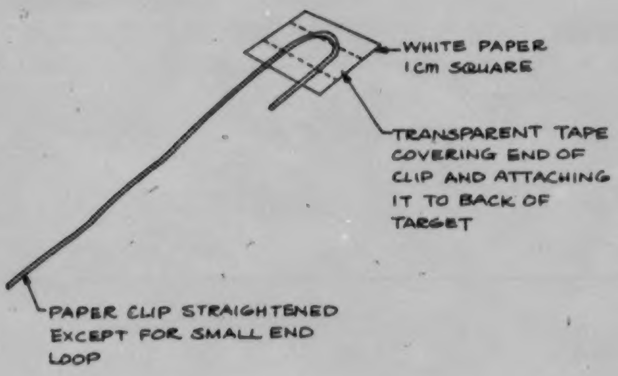
white paper
transparent tape
scissors
paper clip
meter stick
chalk
graph paper

PROCEDURE:

1. Cut out two squares of white paper, 1 cm (± 1 mm) on a side.

2. Prepare one of the squares as indicated in the diagram.

3. Select an area of chalkboard about .75 m wide at the height of the subject's eye level. Tape the second square of paper on the chalkboard in the center of the .75 m-wide area. (If the tape doesn't stick, mark the second square in the center of the chalkboard with white chalk. Fill in the whole square with chalk.)


WHITE PAPER 1cm SQUARE
TRANSPARENT TAPE COVERING END OF CLIP AND ATTACHING IT TO BACK OF TARGET
PAPER CLIP STRAIGHTENED EXCEPT FOR SMALL END LOOP

4. Have the subject stand directly before the white square on the board with his eyes 1 m (± 2 cm) from the board. (Eyeglasses or contact lenses need not be removed.) Have the subject cover his left eye with a hand, and fix the gaze of his right eye on the white square at the center of the board.

5. Move the target along the board from the center point horizontally to the right until the subject no longer sees it. Then bring the target slowly back toward the center to the point at which it reappears. Mark the location with chalk. (Note: make sure that the subject is (a) covering the left eye and (b) keeping the right eye on the central square rather than on the target.)

6. With the subject's gaze fixed on the central spot, move the target into the blind area again and then further to the right until it reappears in his sight. Mark the location with chalk.

7. Repeat the operation in various directions (from above and below the blind spot) to define the two-dimensional limits of the blind spot.

8. Repeat the procedure with the left eye, while moving the target on the left side of the chalkbaord.

9. Plot the results on a graph that indicates the size of blind spot and its distance from the center point. Distances should be measured with the meter stick (or a metric ruler) and indicated on the graph in centimeters. The distance of the subject from the chalkboard should also be recorded.

10. Repeat the procedure with the roles of tester and subject reversed.

DISCUSSION QUESTIONS:

1. Why are no gaps (blind spots) noticeable when both eyes are open?

2. Speculate on whether the technique used in the procedure could be used for mapping the outer edges of the visual fields.

3. Compare the size and location of the blind spot for each eye with the blind spots of others in your class.

ACTIVITY 9: AN INTRODUCTION TO COMPUTER DIAGNOSIS OF BRAIN DISEASE

INTRODUCTION:

In Sections 1 through 8 of the Student Text, you studied the anatomy and physiology of the central nervous system. In the course of this study some of the most common disorders of the brain were discussed, i.e., epilepsy, multiple sclerosis, brain tumor, head injury, cerebral thrombosis and cerebral hemorrhage. Simultaneously, in Mathematics, you have been learning how to analyze logic statements and how to perform a variety of functions, including (1) creating truth tables when given a logic statement, (2) determining the switching functions that correspond to information presented to you in a truth table and (3) determining the circuitry that corresponds to given switching functions. You will be putting all of this knowledge to use in the next week or so as you design and build a computer that will aid you in the diagnosis of brain disease.

In order to progress from a list of diseases and clinical findings to designing a computer that will give you a correct diagnosis based on a set of clinical findings, a number of steps are necessary. The first step is to create a truth table in which the clinical findings related to the diseases in question are the input and the possible diagnosis (or disease) is the output. We say *possible* because usually such a table will not tell us exactly what disease the patient has. Instead it will indicate what the possibilities are so that a physician will know what future testing must be done.

To make the approach clear, let's start out with an example that involves only a few variables. We will take a cold as the example of the disease and sniffles and fever (above 38 °C) as the clinical findings. *Suppose we are given the information that a cold always involves the sniffles and never involves a fever*. In order to construct a truth table, we must first assign a letter to each possible clinical finding. We may choose the following statements.

p: sniffles present
q: fever present

We know that if statement p is true and statement q is false, then a cold is a possible diagnosis. Otherwise it is not a possibility. Truth Table 1 summarizes what we know.

From Mathematics class you know how to find the logical statement corresponding to this table. In order to get an output of 1, finding p must be present and finding q must be absent. Therefore the output is 1 *exactly* when the statement $p \wedge \bar{q}$ is true. This is the diagnostic statement for a cold.

TRUTH TABLE I

INPUTS		OUTPUT
p	q	(possible cold diagnosis)
1	1	0
1	0	1
0	1	0
0	0	0

$p \wedge \bar{q}$: statement for cold.

Table 1 can be represented in a simpler form by combining the three inputs that give an output of 0, as in TABLE 2.

TRUTH TABLE 2

INPUTS		OUTPUT
p	q	(possible cold diagnosis)
1	0	1
all other combinations		0

Now suppose we expand the example to include one other clinical finding, a sore throat. We can use the letter "r" to designate the presence of a sore throat. The new situation can be summarized as follows.

possible findings* - p: sniffles q: fever r: sore throat
possible diagnoses - cold; strep throat

In addition, suppose we are given the following information. A strep throat always involves a sore throat, may or may not involve the sniffles and may or may not involve a fever. Also, a cold may or may not involve a sore throat.

TABLE 3 will help clarify the relationship between findings and diseases.

TABLE 3

	p	q	r
COLD	present	absent	present or absent

	p	q	r
STREP THROAT	present or absent	present or absent	present

Notice that TABLE 3 tells us that sniffles and fever are no help in diagnosing strep throat. Similarly a sore throat is no help in diagnosing a cold.

We can use TABLE 3 to prepare truth tables for a cold and strep throat. The tables are given in short form as in TABLE 2. When a finding can be either present or absent we have indicated the fact by the symbol 1/0.

TABLE 4

COLD

INPUTS			OUTPUT
p	q	r	(possible cold diagnosis)
1	0	1/0	1
all other combinations			0

STREP THROAT

INPUTS			OUTPUT
p	q	r	(possible strep diagnosis)
1/0	1/0	1	1
all other combinations			0

What logical statements (or switching functions) correspond to the diseases now? You can use the same technique as in Mathematics class to find out but you must ignore the letters with entry 1/0. Thus, in the first table, p must be 1 and q must be 0 and we disregard the letter r. The statement for the cold truth table is therefore $p \wedge \overline{q}$. In the strep truth table, r must be 1 and we disregard letters p and q. Hence the statement for the strep truth table is simply r.

$p \wedge \overline{q}$: statement for cold
r : statement for strep

---

*In Activities 9 through 13, we will use the word "findings" to mean "clinical findings"--it will include symptoms, signs and findings.

If the finding of a sore throat is included in our discussion, why doesn't r appear in the statement for a cold? The reason is simple; a sore throat does not help us diagnose a cold, so it need not be considered.

We can combine the two truth tables of TABLE 4 into a single table (TABLE 5).

TABLE 5

INPUTS p	q	r	POSSIBLE DIAGNOSIS
1	0	1/0	cold
1/0	1/0	1	strep
all other combinations			neither

Let us see what this table will yield for a few input combinations [p, q, r]. The combination [1, 1, 1] will yield a possible diagnosis of strep throat, but a cold is eliminated because q is not zero. A combination of [1, 1, 0] gives a diagnosis of "neither."

One last note: it is entirely possible for someone to have both a strep throat and a cold at the same time. The table allows for this possibility. For example, consider an input combination of [1, 0, 1]. This description fits both cold and strep throat, and the patient may have either disease or both of them.

CONSTRUCTING A DIAGNOSTIC TRUTH TABLE FOR BRAIN DISEASE:

It is now time for you to begin the construction of the truth table that you will use to design the circuits of a diagnostic computer. Information on five brain diseases and findings you have studied thus far in this unit are summarized below. Each finding has been assigned a specific letter. In addition, there is a statement for each disease, telling you how each of the findings listed relates to that disease. Read through the material and then perform the Procedure steps on a separate sheet of paper. Keep your work well organized--you will be using the tables you construct in later activities.

FINDINGS:

a: convulsions
b: continuing brain dysfunction
c: blood in CSF
d: high CSF protein concentration
e: high CSF globulin concentration
f: high CSF pressure
g: rapid onset
h: slow onset
i: progressive onset
j: abnormal skull X-ray

DISEASES:

Grand mal epilepsy always includes convulsions and shows rapid onset; and never includes continuing brain dysfunction, CSF abnormalities, slow or progressive onset or abnormal skull X-rays.

Multiple sclerosis always shows slow onset and continuing brain dysfunction, may or may not include high CSF globulin and protein concentration, and never involves the other remaining findings.

Cerebral hemorrhage always shows continuing brain dysfunction and rapid onset; may or may not include convulsions, blood in CSF, high CSF protein concentration or high CSF pressure; and never involves the remaining findings.

3

Cerebral thrombosis always shows continuing brain dysfunction; may or may not show convulsions, rapid onset, slow onset or progressive onset; and never involves the remaining findings.

Brain tumor always shows continuing brain dysfunction; may or may not show convulsions, blood in CSF, high CSF protein concentration, high CSF pressure, rapid onset, slow onset or abnormal skull X-rays; and never shows the remaining findings.

PROCEDURE:

1. Write the simplified truth table for each of the five diseases. Include information on all 10 of the possible findings.

Example:

FINDINGS										
a	b	c	d	e	f	g	h	i	j	
1/0	1	1/0	1/0	0	1/0	1/0	1/0	0	1/0	Brain Tumor

2. Use the truth tables to write a logical statement for each disease.

Example: Brain tumor: using the truth table in Step 1, we get $b \wedge \overline{e} \wedge \overline{i}$.

3. Combine all the simplified truth tables into one complete diagnostic truth table, as was done for cold and strep throat in TABLE 5 in the Introduction.

4. Use the truth table you have constructed to determine the diagnosis(es) that are possible for each of the following sets of findings. Record your answers.

DISEASE POSSIBILITIES	FINDINGS									
	a	b	c	d	e	f	g	h	i	j
?	0	1	0	1	0	1	0	1	0	1
?	1	1	1	1	1	1	1	1	1	1
?	0	1	0	0	0	0	1	0	0	0

LABORATORY ACTIVITY 10: LOGIC GATES

GENERAL INTRODUCTION:

In this activity you will become familiar with the actual structure and operation of the logic gates you will be using to build your diagnostic computer. The gates are mounted on printed-circuit (PC) cards. In the center of every PC card is a housing that contains an integrated circuit with 14 electrical terminals, 7 on each side (Figure 1).

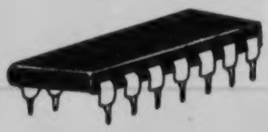


FIGURE 1: Housing and terminals of an integrated circuit.

Let's start out by taking a look at a diagram of a complete PC card (Figure 2). This one is a "2-AND" card. The "2" in front of the "AND" means that each AND gate on this card has two inputs. (You will see cards later with gates having more than two inputs.) The card is labeled on both sides with its name. On the underside of the card you will also find positive and negative markings (+ and -). This card has four separate 2-AND gates on it. Here is what one of them looks like (Figure 3).

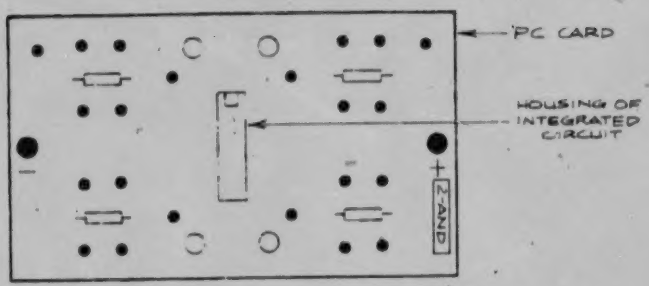

PC CARD
HOUSING OF INTEGRATED CIRCUIT
−
+
2-AND

FIGURE 2: A 2-AND PC card.

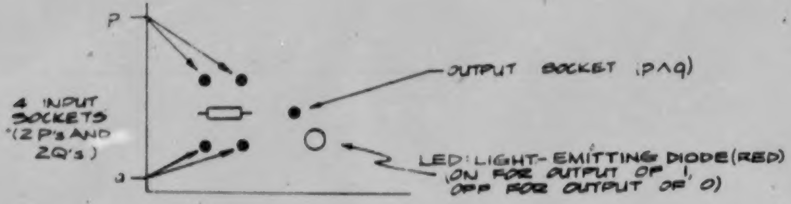

p
q
4 INPUT SOCKETS (2 P's AND 2Q's)
OUTPUT SOCKET (p∧q)
LED: LIGHT-EMITTING DIODE (RED) (ON FOR OUTPUT OF 1, OFF FOR OUTPUT OF 0)

FIGURE 3: Components of a 2-AND gate.

The gate shown has two basic inputs, p and q. However, notice that there are two input sockets for p. If you look at the underside of the PC card you will see that these two sockets are connected by copper foil. This means that the two sockets are electrically the same. So a single wire placed in either p socket will provide the p input. The same is true for the q input. (This set-up allows you to route the inputs p and q to other gates if desired.)

The gate (Figure 3) also has an output socket with switching function $p \wedge q$ (because it is an AND gate). Next to the output socket is a light-emitting diode (LED) which tells you what the output of the gate is. If the output is 1, the LED will light up. If the output is 0 it will not be lit.

Now let's look at the whole 2-AND card again (Figure 4).

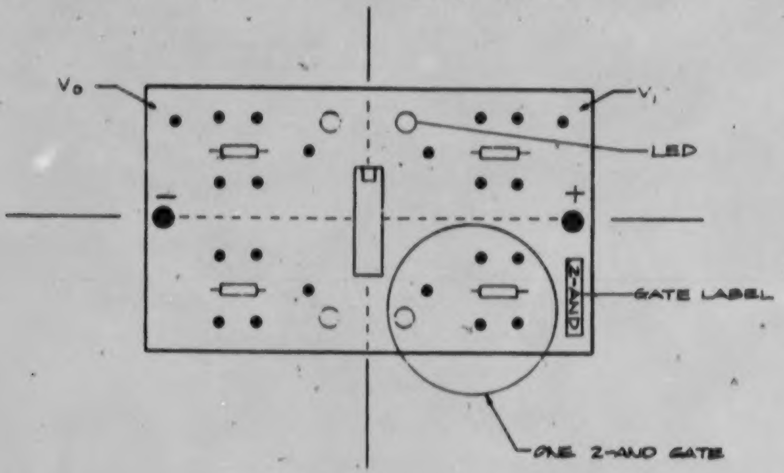


FIGURE 4: A 2-AND PC card showing connecting sockets V_0 and V_1.

Notice that each quarter of the card has a separate 2-AND gate. Also notice that you can quickly tell how many gates are on a card merely by counting the number of LED's--there is one LED for each gate. Each PC card also has sockets connected directly to the supply voltage source (V_0 and V_1).

The PC cards for all four of the 2-input gates you studied in Mathematics class have the same general appearance. The gates are

2-AND	2-OR
2-NAND	2-NOR

Normally you can tell which gate you have by checking the label on the margin of the PC card. Each of these 2-input cards has four separate gates on it. In this activity, some of the PC cards will have the gate labels covered--do not remove these labels until instructed to do so.

The card for INVERT gates looks quite different. A single INVERT gate is shown schematically in Figure 5. It has one input (p) and one output ($\bar{p}$). As with the PC cards already discussed, the input has two sockets which are electrically the same. (A single wire in either p socket will provide the p input.) The output of an invert gate consists of a socket and a LED just as with the gates previously discussed. An INVERT card has six separate invert gates, instead of four.

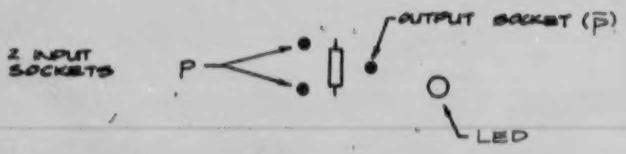


FIGURE 5: Components of an INVERT gate.

There is one more card you need to know about. It is called a pulser card. A diagram of a portion of a pulser card is shown in Figure 6.

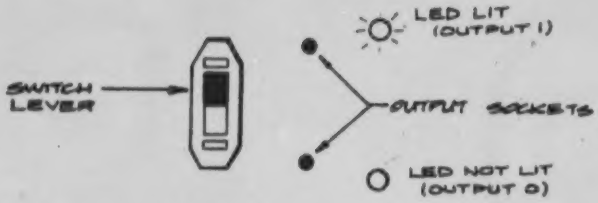


FIGURE 6: Components of a pulser.

The switch shown provides an output of 1 to the output socket on the same side as the switch lever (and lights the LED on that side). The output socket on the opposite side of the switch lever (the "off" position) provides an output of 0 (and the LED on that side is not lit). In Figure 6 the switch is "up" so the upper output socket is at level 1 and the upper LED is lit--the lower socket has an output of 0. There are two pulsers on each pulser PC card. In this activity, the two pulsers will provide inputs to the other gates.

The PC cards are mounted on a special Masonite board called a "brain" frame (Figure 7), and then voltage is supplied to the cards by the BIP. Up to a dozen cards can be mounted on one frame.

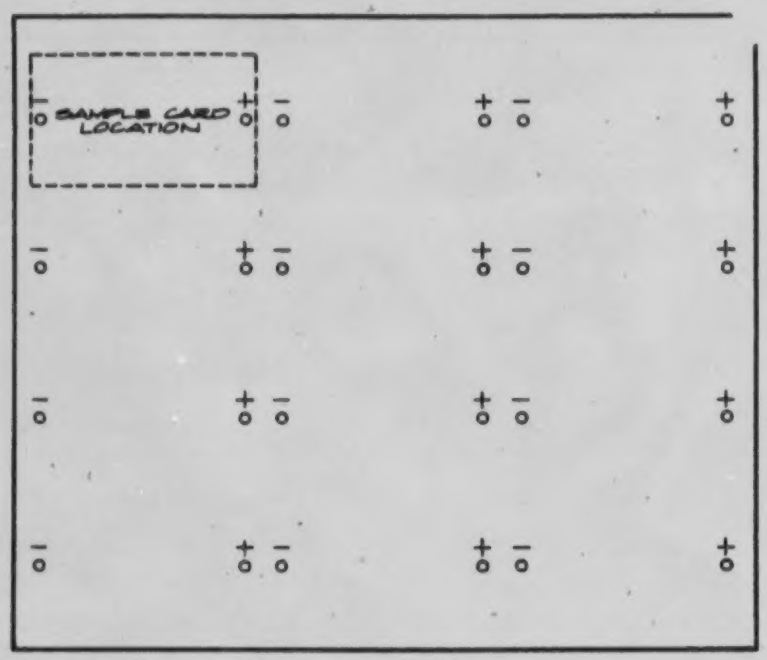


FIGURE 7: A card mounted on a "brain" frame.

The various components--gates, pulsers, etc.--can be interconnected by lengths of insulated wire with about 5 mm of insulation stripped from each end. Be sure the end of the wire is straight before you try to insert it into a socket. Try not to break off a wire inside a socket. (But, if you do, remember that in the case of an input socket, you still have a second socket that can be used.)

PART I: IDENTIFYING LOGIC GATES FROM TRUTH TABLES

INTRODUCTION:

Since you are already familiar with the truth tables for the various logic gates, it would not be much of a challenge to ask you to figure out what the truth table for a 2-NAND gate is; you already have that information. Instead, in this activity, you will be given a series of logic gates, but you will not be told what kind of gates they are. It will be your job to connect them to the BIP and determine what the truth table for each one is. Then by comparing the truth table you obtain with those you have been given previously, you will identify the gate as either a NAND, NOR, OR or AND gate.

MATERIALS:

BIP
"brain" frame (with thumb nuts)
pulser card

"unknown" cards
wire
wire cutter-strippers

PROCEDURE:

1. Set a brain frame on your desk or table as shown in Figure 7. The screws should be pointing upward.

2. Install the pulser card in the upper-left corner of the brain frame. (See Figure 7.) The end of the card marked "+" should be at the right and the end marked "-" at the left. (The "+" and "-" are on the underside of the card, but you should be able to see them through the card.) Another useful fact is that the gate labels are always on the "+" side. IMPORTANT! ALL CARDS MUST ALWAYS BE INSTALLED WITH THE "+" SIDE AT THE RIGHT. OTHERWISE, WHEN THE FRAME IS CONNECTED TO THE BIP, THE CARD MAY BE RUINED.

Screw on the thumb nuts firmly to insure good electrical contact between the card and the frame. If the card won't fit properly on the screws, inform your instructor.

3. Connect T to X on the BIP programming panel.

4. Connect the "W" terminal on the BIP to the pin in the upper-left corner of the pulser card. Connect the "S" terminal on the BIP to the pin in the upper-right corner of the pulser card. Plug in the BIP.

5. If no LED's are lit on your pulser card, there is something wrong with either the pulser card or the BIP. Make the following checks.

a. Is one LED on the BIP panel lit? If so the BIP is functioning.

b. If the BIP is functioning, something is wrong with the pulser card or the way you have connected the card to the BIP.

c. Is the pulser card positioned correctly on the brain frame? Are the connections from the BIP to the card made correctly?

d. You can check your pulser card by mounting it on another nearby brain frame. If you still have no lit LED's, the card may be defective. If the LED's light up on another frame, the card is functional, but the problem lies elsewhere. You should consult your instructor.

6. Install one of your unknown cards in a position near the pulser card. Remember to place the "+" side of the card to the right and the "-" side to the left. At this point you may find that the output LED's on the unknown gates light up. This

may seem surprising since there are no wires connected to the card yet. However, the entire brain frame was activated when you performed Step 4. The voltage of the frame is now "floating" at 1. This means that your gates are automatically receiving a 1 in both inputs. Depending upon the kind of gates they are, the outputs may be 1. You will see this phenomenon many times as you work with the PC cards. The "floating" 1 will be eliminated as soon as you connect wires to the input sockets of a gate.

7. Connect one output socket of each of the two pulsers to the two separate input sockets of one of the four gates on the unknown gate card. When you have completed this step you should have something similar to the set-up shown in Figure 8.

Important: DO NOT connect the two wires from the pulser card into two sockets that represent the same input (are electrically the same) to the gate. This will damage the gate.

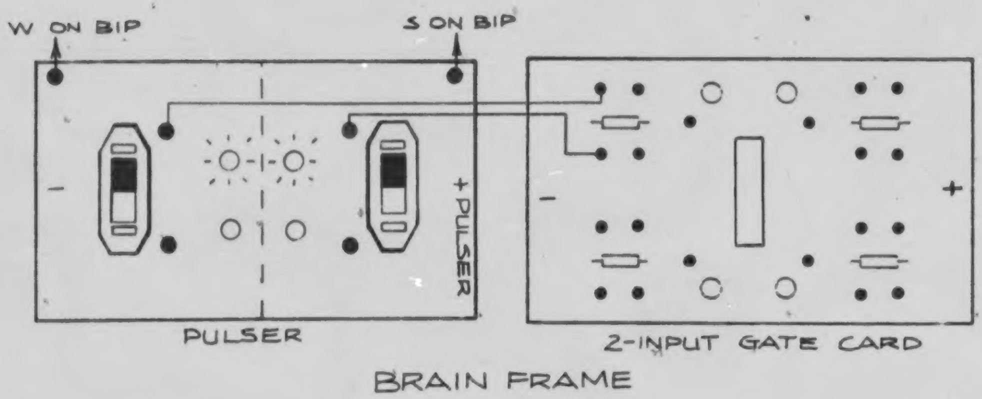


FIGURE 8: How to attach the pulser card and unknown gate card to the brain frame. In the example shown, the pulsers are inputting the truth vector [1,1] to the gate.

8. Establish the truth table for the unknown gate you have chosen by determining the output for each of the four possible positions of the two switches on the pulser card. Record your findings as in Table 1.

To establish the truth table first adjust both pulser switches to provide inputs of 1 to the gate. This is done by moving each pulser switch lever to the side of the card with the wire going to the unknown gate (see Figure 8). Then check to see whether the gate's LED is lit. If it is the output is 1, if it is not the output is 0. Record your findings in the first row of the truth table. Next, adjust the pulser switches so that one provides an input of 1 and the other an input of 0. Again, check the gate LED. Continue to go through all four possible combinations of inputs, recording the corresponding outputs of the gates as you proceed. When you are finished you should have completed a table similar to Table 1.

TABLE 1 : TRUTH TABLE FOR AN UNKNOWN GATE

INPUTS (Provided by pulsers)		OUTPUTS (Gate LED on = 1; off = 0)
1	1	?
1	0	?
0	1	?
0	0	?

9. Identify the unknown gate you have just tested by comparing its truth table with those shown in Table 2. Disconnect the unknown gate from the brain frame and remove the paper covering the label.

10. Take turns with the other students in your group in repeating Steps 6 through 9 for the other unknown gates.

TABLE 2 : TRUTH TABLES FOR 2-INPUT GATES

INPUTS		OUTPUTS AND	OUTPUTS NAND
p	q	$p \wedge q$	$\overline{p \wedge q}$
1	1	1	0
1	0	0	1
0	1	0	1
0	0	0	1

INPUTS		OUTPUTS OR	OUTPUTS NOR
p	q	$p \vee q$	$\overline{p \vee q}$
1	1	1	0
1	0	1	0
0	1	1	0
0	0	0	1

PART II: USING INVERT GATES TO CHANGE THE SWITCHING FUNCTION OF A GATE

INTRODUCTION:

In the first part of this activity you worked at identifying a number of unknown gates by determining what their truth tables were. Each of these gates has a switching function which will be useful to you in constructing the diagnostic computer. However, you may not always have a sufficient number of one type of gate. In such instances, you will have to use a combination of other gates to create the desired circuit.

It is possible to produce the switching function of any 2-input gate by combining any other 2-input gate with INVERT gates in an appropriate way. In this portion of the activity you will see how this is done.

MATERIALS:

BIP	pulser card
brain frame (with thumb nuts)	2-NAND card

2-AND card	INVERT card
2-OR card	wire
2-NOR card	wire cutter-strippers

PROCEDURE:

1. Connect a 2-AND gate to the pulser as described in Step 7 of Part I. Next invert the output of the gate by connecting the output socket of the 2-AND gate to the input of an INVERT gate as shown in Figure 9. Then construct a truth table and fill it in by recording the output of the INVERT gate for each of the four possible positions of the two switches on the pulser card. Record your findings.

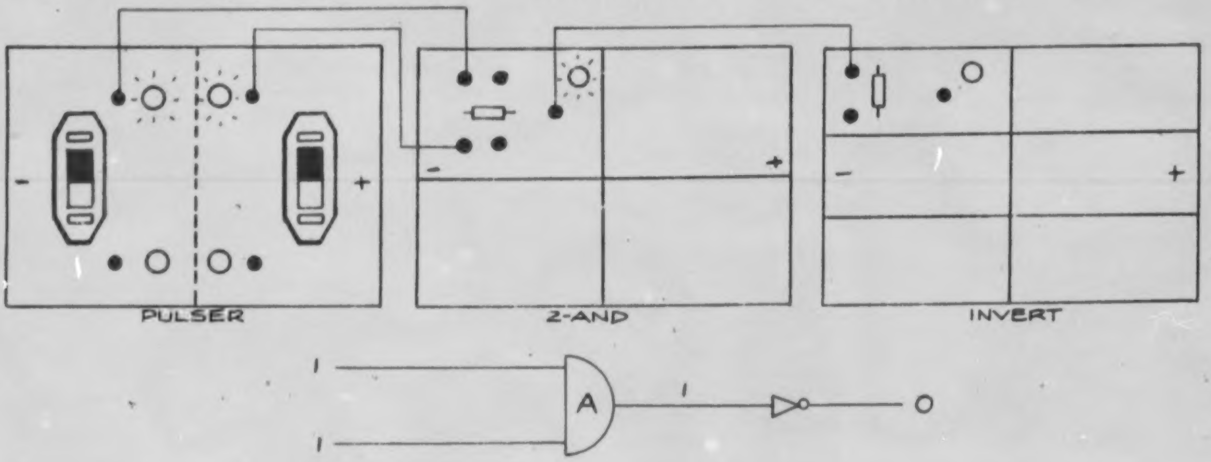


FIGURE 9: Wiring for a 2-AND gate with output inverted. The pulsers are inputting the truth vector [1,1] to the 2-AND gate.

2. Identify the 2-input gate that has the same switching function as a 2-AND gate with its output inverted. Record this information.

3. Remove the 2-AND gate from the brain frame and replace it with a 2-OR gate. Repeat Steps 1 and 2 for this gate.

4. Repeat Step 3 for the 2-NOR and 2-NAND gates.

5. Determine the truth table for a 2-AND gate with both inputs inverted. You will need to use two different INVERT gates as shown in Figure 10.

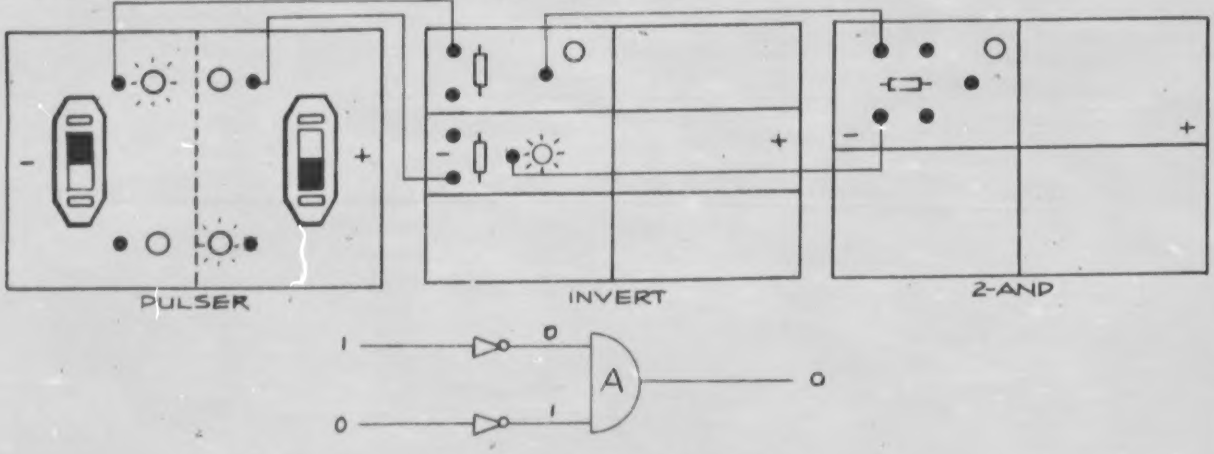


FIGURE 10: Wiring for a 2-AND gate with inputs inverted.

6. Identify the 2-input gate that has the same switching function as the 2-AND gate with both inputs inverted. Record this information.

7. Repeat Steps 5 and 6 for the 2-NAND, 2-OR and 2-NOR gates.

8. Determine the truth table for a 2-AND gate with both inputs inverted and output inverted, as shown in Figure 11.

The layout will look much like Figure 10 but you will need to run another wire from the output socket of the 2-AND gate to the input socket of a third INVERT gate. When you construct your truth table you will be reading the LED on the final INVERT gate.

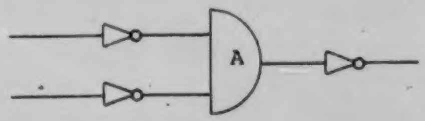


FIGURE 11: An AND gate with inputs and output inverted.

9. Identify the gate that has the same switching function as a 2-AND gate with both inputs and output inverted. Record your answer.

10. Repeat Steps 8 and 9 for the 2-OR, 2-NOR, and 2-NAND gates.

11. Save the data sheets you have constructed for later use.

DISCUSSION QUESTIONS:

1. Why is it necessary to install all PC cards with the end marked "+" on the right?

2. Observe a 2-NAND card. How many of each of the following does it have? LED's, housings, input sockets, output sockets.

3. How does a pulser card differ from a gate?

LABORATORY ACTIVITY 11: A COMPUTER CIRCUIT FOR TWO DISEASES AND THREE FINDINGS

INTRODUCTION:

When you design your computer for diagnosing brain disease, you will be working with five diseases and numerous findings. This activity will give you practice in the design of circuits. The procedure is the same as the one you will use to construct a computer for diagnosing brain diseases, but the number of variables is smaller. You will work with only two diseases and three findings. In this way, you will become familiar with some of the techniques to be used on the brain-disease computer, while working with a simpler circuit.

The diseases to be considered in this activity are a cold and a strep throat--as in Activity 9. The simplified truth table for the two diseases looks like this.

FINDINGS			POSSIBLE DIAGNOSES
sniffles p	fever q	sore throat r	
1	0	1/0	cold
1/0	1/0	1	strep

We can also state the conditions necessary for each disease in terms of symbolic logic.

cold: $p \wedge \bar{q}$
strep: r

The problem is to develop a diagnostic circuit for each disease. For example, when the inputs to the "cold" circuit are $p = 1$, $q = 0$, the LED should go on. (No r input is needed, since it makes no difference, as far as a cold goes, whether r is 1 or 0.) One circuit that will do the job is shown in Figure 1. If p is at level 1 (sniffles present) and q is at level 0 (no fever), the 2-AND gate will have two 1's as inputs and therefore give a 1 as an output. So if the LED for this AND gate lights up, a cold is indicated.

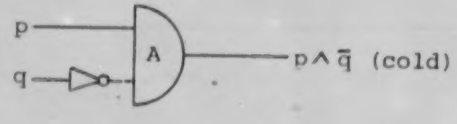


FIGURE 1: Circuit for diagnosing a cold.

To prepare for future computer activities, we are going to make a minor modification in this circuit. When dealing with five diseases, it is confusing to have the various LED's at scattered locations on the brain frame. Instead, the various outputs will be fed into the INVERT gates on a single INVERT card (diagnosis card) that will be used specifically to register the diagnoses. Then the possible diagnoses can be determined by checking the LED's on a single PC card.

In Problem Set 11 you reviewed how to design a circuit with a final INVERT gate. The circuit for the example of a cold looks like this.

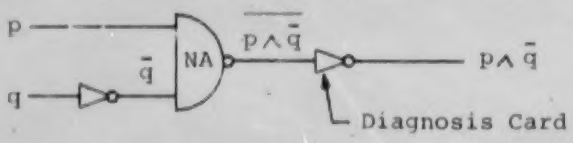


FIGURE 2: Alternate circuit with INVERT diagnosis card.

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Similarly, the simplest circuit for a strep throat involving a diagnosis card is this one.

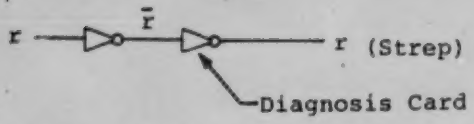

FIGURE 3: Circuit for diagnosing strep throat.

As discussed in Problem Set 11 (Part I), there are several ways to create equivalent circuits by using different gates. For example, the circuit in Figure 3 is equivalent to the one in Figure 4.

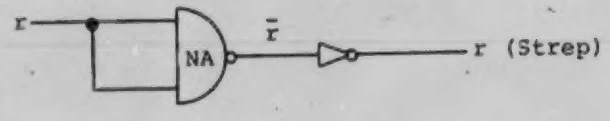

FIGURE 4: Alternate "strep" circuit.

The two inputs of the NAND gate have been connected. Therefore both inputs are equal to r. The output of the gate is $\overline{r \wedge r}$ which is the same as $\bar{r}$. The gate now behaves like an INVERT gate. In other words, the output is the opposite of the input.

In order to make this connection for a 2-input gate, we insert a wire in the socket next to the r input wire. Then we insert the other end of the wire in a socket for the second gate input. See Figure 5. Both inputs to the gate are now electrically the same.

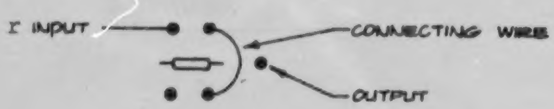

FIGURE 5: How to provide the same input to both input sockets of a 2-input gate.

Figures 2 and 3 show circuit diagrams for each of the two diseases under consideration: cold and strep throat. We will now combine these diagrams into a single diagram. We begin by splitting each input wire (p, q, r) into two wires with an INVERT gate on one of them.

Look at the wiring below input p in Figure 6. The left wire has truth value p but the right wire passes through an INVERT gate and therefore has truth value $\bar{p}$. The same is true of the other two inputs. We now have six inputs available: p, $\bar{p}$, q, $\bar{q}$, r and $\bar{r}$.

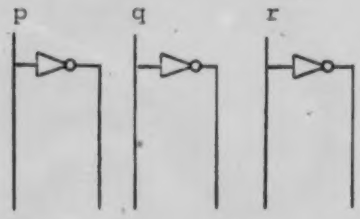

FIGURE 6: Combining circuits for cold and strep diagnosis.

We complete the diagram by connecting the proper input wires to the appropriate gates. The circuit in Figure 2 for a cold requires inputs of p and $\overline{q}$ to the NAND gate, so we connect wires to the p and $\overline{q}$ input lines. The circuit in Figure 3 for strep requires an input of $\overline{r}$, so we connect the $\overline{r}$ wire to the INVERT gate. The result is shown in Figure 7.

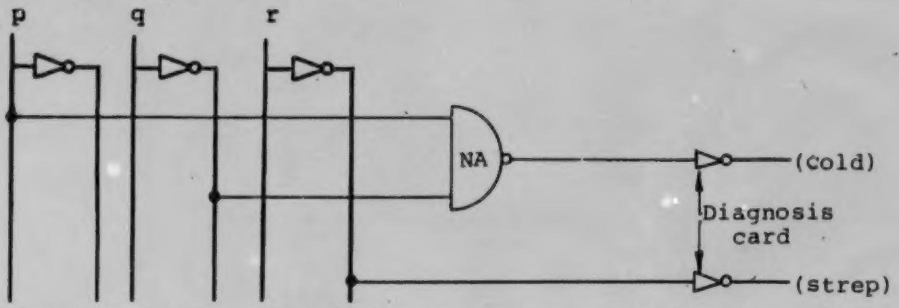

FIGURE 7: Combined circuit for cold and strep diagnosis.

Since this activity (as well as the brain-disease computer) will require more inputs than one pulser card can supply, a special input card will be used instead. It is labeled TRUTH TABLE (Figure 8).

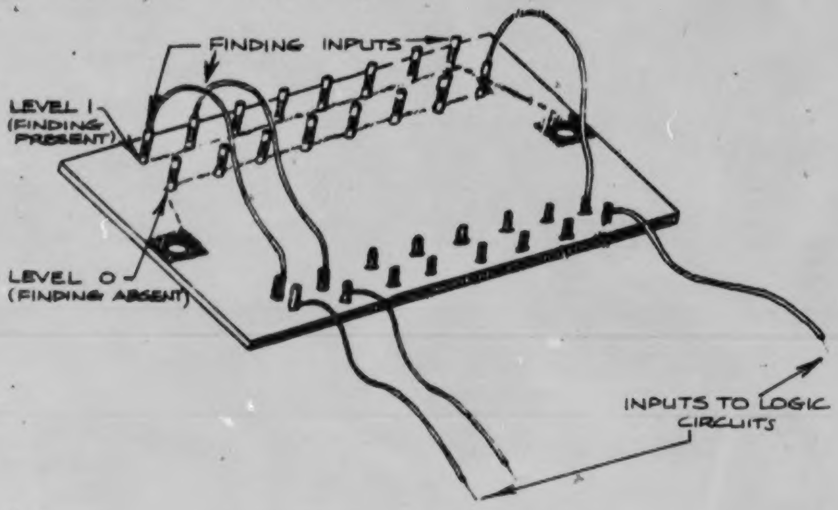

FIGURE 8: TRUTH TABLE card.

If you look at the underside of this card, you will see that the eight input sockets in the upper row (level 1) are all interconnected. The same is true of the second row. This card has no + and - signs at the edges and could be installed with the input sockets at either the top or the bottom of the card.

We recommend that the TRUTH TABLE card be installed each time you use it with the input sockets at the top (see Figure 8). In this case, every socket in the upper row will provide an input at logic level 1, and every socket in the second row will provide an input at logic level 0. Each lead on the card may be plugged into either level 1 or level 0.

In the drawing of the card the two leads at the bottom left will carry logic level 1, and the lead at the far right will carry logic level 0, if the card is installed as directed. The other ends of the leads serve as the inputs to the logic circuits. (Notice that the card has room for eight leads.)

MATERIALS:

BIP and brain frame	2 INVERT cards
2-NAND card	wire
TRUTH TABLE card	wire cutter-strippers

PROCEDURE:

1. Install the following cards in the brain frame. (Remember to place the "+" side of each card on the right.)

   a. the TRUTH TABLE (TT) card, which will supply inputs based on the presence or absence of findings--input sockets at the top

   b. an INVERT card for inverting finding inputs, as shown schematically at the top of Figures 6 and 7

   c. the 2-NAND card for the "cold" circuit

   d. an INVERT card for registering the diagnoses

2. Draw a map of your brain-frame set-up (see Figure 9). This map will be needed for designing the diagnostic computer. First, label the position of each card on your map. Use the upper edge of the appropriate space on the brain-frame map for this. Then use dashed lines to divide each INVERT card on the diagram into six regions (one for each gate) and the 2-NAND card into four regions.

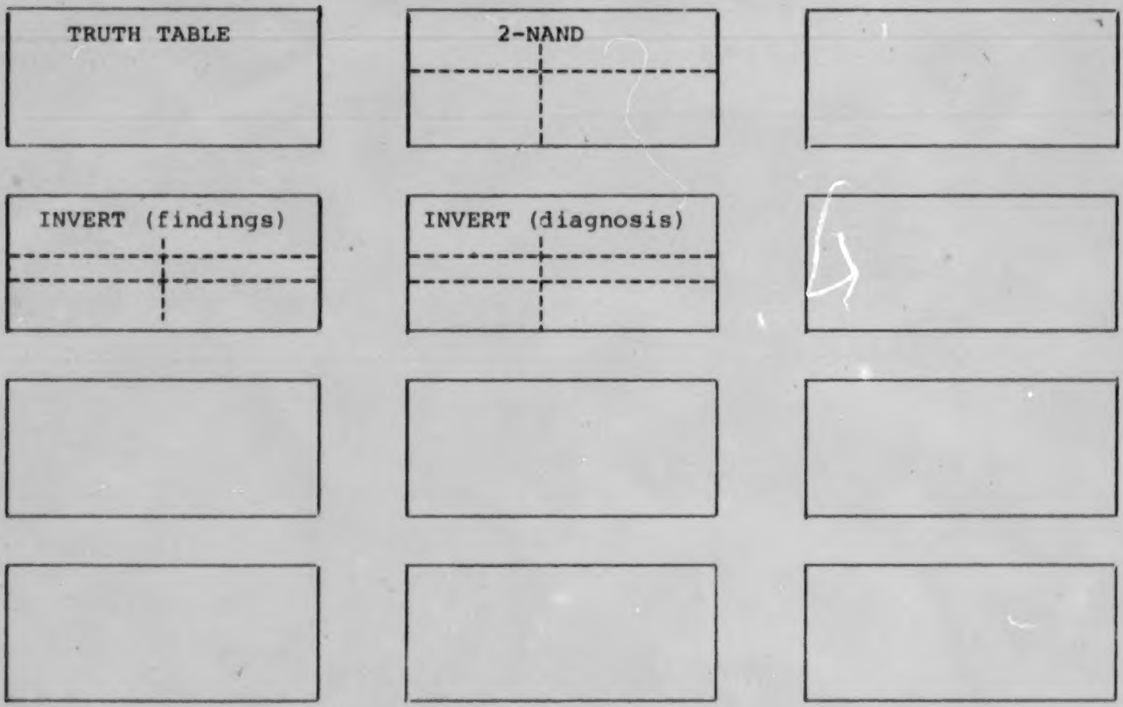

FIGURE 9: Sample brain-frame map.

3. Divide the TRUTH TABLE space on your diagram into eight regions. Decide which outputs of the TT card you will use for each finding. Label your map accordingly. For example, see Figure 10.

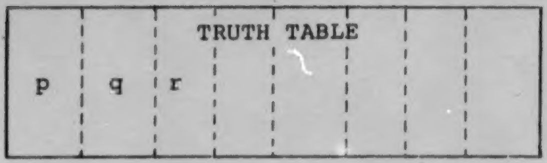

FIGURE 10: Labeling TRUTH TABLE card. (example)

4. Decide which outputs on your diagnosis card you will use to register each disease, and label them on your brain-frame map. For example, see Figure 11.

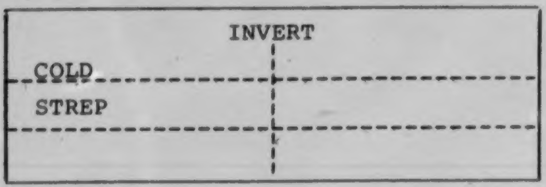

FIGURE 11: Labeling INVERT diagnosis card.

5. Connect the p, q and r leads coming from the lower portion of the TT card to the input sockets of three separate INVERT gates on the card you are using for inverting finding inputs. Label these three gates on your map with their inputs. An example is shown in Figure 12.

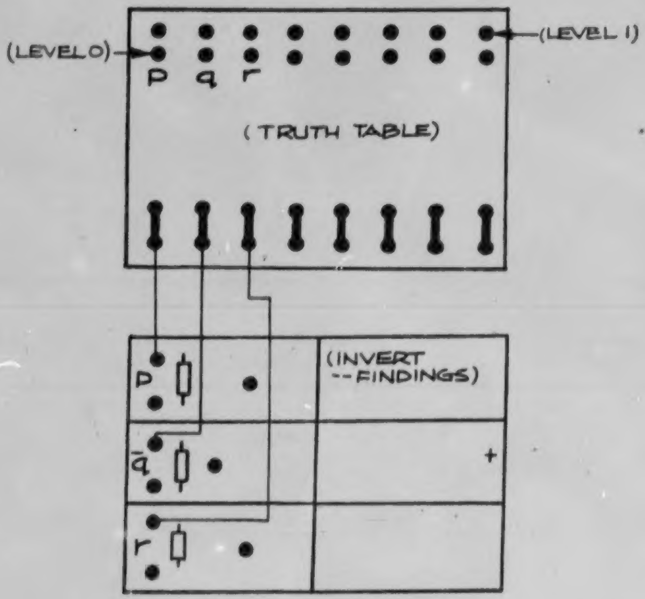

FIGURE 12: Sample arrangement of TT card and INVERT card for inputting findings.

Notice that each of the three INVERT gates still has one unused input socket available (Figure 12). This socket can be used to carry the original input to anywhere you need it (see Figure 13). The output socket can be used to carry the inverted input to wherever you need it.

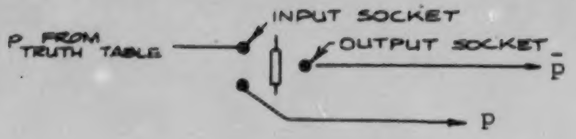

FIGURE 13: Using second input socket of a gate to reroute finding input to another gate.

6. You are now ready to complete the circuits for each of the two diseases. Look back at the combined circuit for the diseases in the Introduction (Figure 7). Try completing the "cold" circuit without reading the next few steps. After you have finished, then read the steps that follow and compare them with what you have done, making changes in your wiring, if necessary.

7. Connect the available input socket of your p INVERT gate to one input socket of a 2-NAND gate. This will provide an input of p to the NAND gate.

8. Connect the output socket of the q INVERT gate to the other input of the same 2-NAND gate. This will provide an input of $\bar{q}$.

9. Label the input sockets of the 2-NAND gate appropriately on your brain-frame map. You should show one of the two arrangements in Figure 14, depending upon how you made the connections.

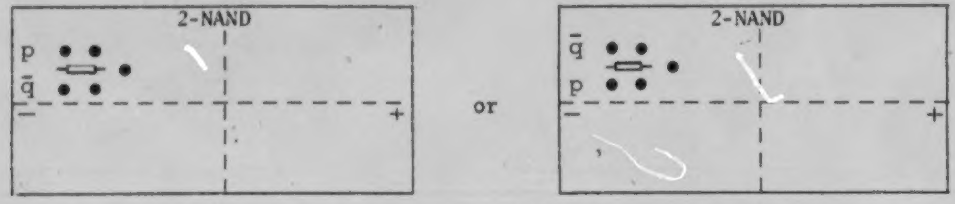

FIGURE 14: Labeling inputs to a 2-NAND gate on the brain-frame map.

10. Connect the output socket of the same 2-NAND gate to an input socket of the INVERT gate you have chosen for "cold" on your INVERT diagnosis card.

11. Connect T to X on the BIP programming panel. Then connect the W terminal on the BIP to the upper-left corner socket of any of the gate cards mounted on the brain frame. (In Figure 15 we used the 2-NAND card.) Connect the S terminal of the BIP to the upper-right corner socket of the same card. The "cold" circuit is now ready to test. The circuitry should be similar to that shown in Figure 15 on the following page.

12. Plug in the BIP.

13. Test your "cold" circuit. On your TT card, plug the p lead into the 1 socket and the q lead into the 0 socket. The "cold" LED on your diagnosis card should be lit. If it is not lit, recheck your circuit.

14. Try completing the circuit for strep throat without reading Step 15. Then read the instruction and make changes, if necessary.

15. The simplest way to complete the "strep" circuit is to connect the output socket of the r INVERT gate directly to an input socket of the INVERT gate you chose for "strep" on your diagnosis card.

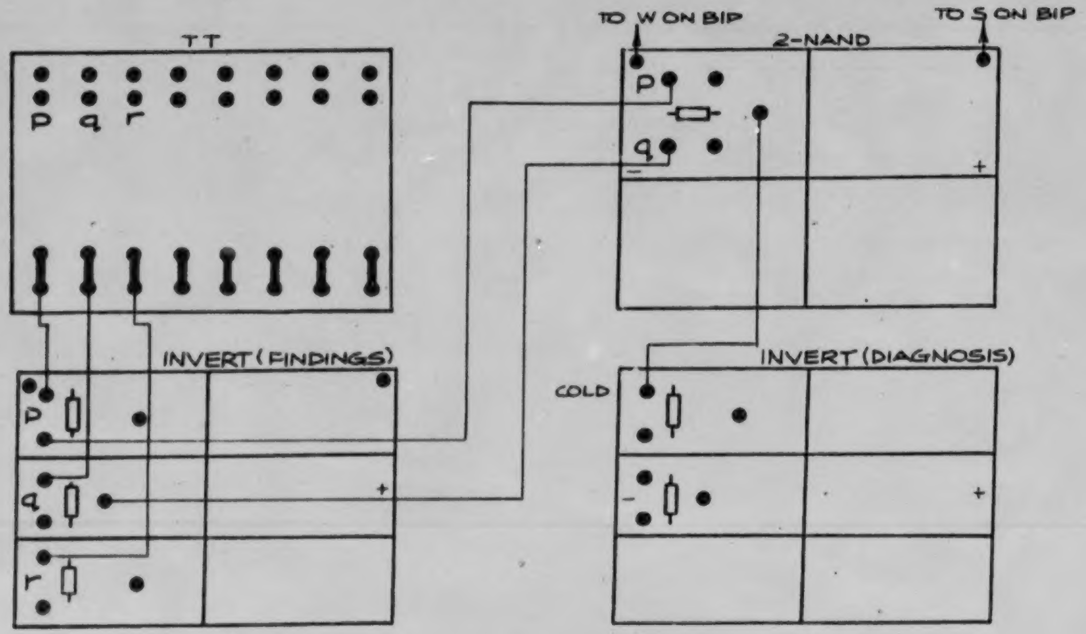

FIGURE 15: "Cold" circuit ready for testing.

16. Test your "strep" circuit by plugging the r lead on the TT card into the 1 socket.

17. If everything appears to be working properly, design and complete a truth table showing all eight possible arrangements of the p, q and r leads on the TT card, and the corresponding diagnoses.

ACTIVITY 12A: SIMPLIFYING THE BRAIN-DISEASE TRUTH TABLE

INTRODUCTION:

In this activity you will simplify the truth tables that you prepared in Activity 9. Simplification will make it easier to construct a computer.

The input to the brain-disease computer will be by means of the TRUTH TABLE card, which can handle up to eight findings. However, the truth table you constructed in Activity 9 included ten findings. This means that at least two of them must be eliminated.

Since you will be setting up the computer with other students, you should confer on this activity. The final outcome must be a truth table that all of you agree on.

PROCEDURE:

1. Review the findings that are listed in the truth table you developed for Activity 9. Determine which findings may be eliminated. You may eliminate the following kinds of findings.

a. A finding that is the exact opposite of another finding. For example, if "fever" were a finding, "normal temperature" would be redundant, since "normal temperature" would simply be the "absence of a fever."

b. A finding that always accompanies another finding. For example, "sugar in the urine" will always be present when there is "elevated blood sugar," so one of the two findings may be eliminated.

2. Consider each of the remaining finding columns to decide how useful they are. If the finding is present how many diseases can you eliminate? If it is absent how many diseases can you eliminate? How many entries are 1/0? (A 1/0 is often useless in distinguishing diseases). These factors all help determine the value of a finding in reaching a diagnosis.

3. When you have reduced the number of findings to eight, experiment with different combinations of findings and see what diagnoses result. See if you can discover a set of findings that will point positively to four of the five diseases. (This is not possible for one of them.) If you cannot, consider replacing one or more of the symptoms by others that will provide such diagnoses.

4. If you should end up with fewer than eight findings, reinstate any discarded findings that may give some improvement in your diagnosis.

5. Record your final truth table.

LABORATORY ACTIVITY 12B: MORE ON LOGIC GATES

INTRODUCTION:

The logic gates you have been working with so far have all been 2-input gates. When a large number of findings are involved, the use of 2-input gates becomes cumbersome. When you design the brain-disease diagnostic computer, you will be dealing with as many as eight findings at one time. There are two other logic gates that will be useful for this purpose, the 4-NAND and the 8-NAND gates.

You were introduced to the 4-NAND and 8-NAND gates in Mathematics Section 5. At that time you were told that these gates respond in the same manner as a 2-NAND gate, i.e., only when all the inputs are 1 is the output 0. The truth tables for 4-NAND and 8-NAND gates are shown below.

TRUTH TABLE FOR 4-NAND GATE

INPUTS				OUTPUT
a	b	c	d	
1	1	1	1	0
all others				1

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TRUTH TABLE FOR 8-NAND GATE

INPUTS								OUTPUT
a	b	c	d	e	f	g	h	
1	1	1	1	1	1	1	1	0
all others								1

The switching functions for the 4-NAND and 8-NAND gates are the following:

4-NAND $\overline{a \wedge b \wedge c \wedge d}$

8-NAND $\overline{a \wedge b \wedge c \wedge d \wedge e \wedge f \wedge g \wedge h}$

Figure 1 shows what a 4-NAND gate and an 8-NAND gate look like on a PC card. Note that the PC card for a 4-NAND gate has two gates on it, while the one for an 8-NAND gate has only one. The letters shown on the cards in Figure 1 designate inputs coming from a TT card. As with all the other logic gates, each input socket has a duplicate socket right beside it that can be used to carry the original input to a second location.

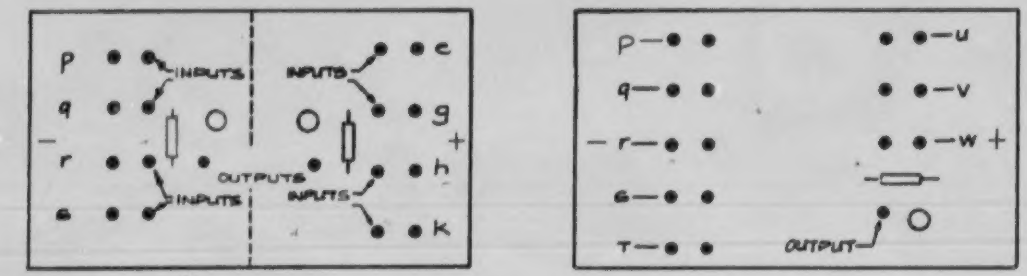
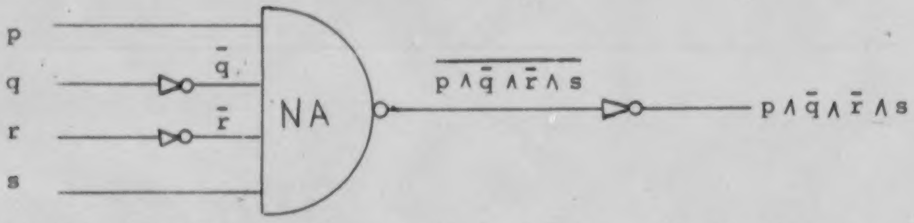
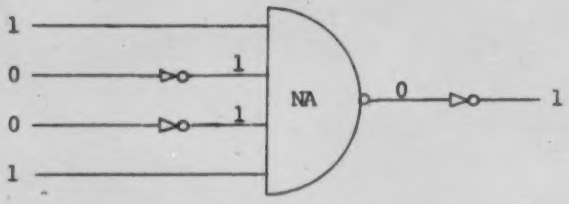

p
q
r
s
INPUTS
INPUTS
OUTPUTS
INPUTS
INPUTS
c
g
h
k
−
+
p
q
r
s
t
u
v
w
−
+
OUTPUT

FIGURE 1: A 4-NAND and an 8-NAND gate.

As an example of the use of a 4-NAND gate, suppose you want a diagnostic circuit for a disease with logical statement $p \wedge \bar{q} \wedge \bar{r} \wedge s$. The circuit is shown below with switching functions and an INV (diagnosis) gate.


p
q
r
s
$\bar{q}$
$\bar{r}$
NA
$\overline{p \wedge \bar{q} \wedge \bar{r} \wedge s}$
$p \wedge \bar{q} \wedge \bar{r} \wedge s$

We can check this circuit to make sure that the output is 1 only when the proper combination of findings occurs. We want an output of 1 only when the statement $p \wedge \bar{q} \wedge \bar{r} \wedge s$ is true, that is when [p, q, r, s] = [1, 0, 0, 1]. The circuit is drawn again on the following page with these particular inputs.



Notice that no other combination of inputs will give an output of 1 because the 4-NAND gate has an output of 0 only when all its inputs are 1.

In Part I of this activity you will test a 4-NAND and an 8-NAND gate to determine whether the truth tables given earlier are indeed representative of the way in which the gates respond to various combinations of inputs. You will also convert an 8-NAND gate to a 6-NAND gate and determine the corresponding truth table.

Part II of the activity deals with creating equivalent circuits using different combinations of gates. Again, we point out the importance of proficiency in this technique, since the number of gates available to you for constructing the diagnostic computer is limited, and it will be necessary to construct alternate circuits.

MATERIALS:

- BIP
- brain frame
- TT card
- 3 INVERT cards
- 4-NAND card
- 8-NAND card
- 2-AND card
- 2-OR card
- 2-NOR card
- 2-NAND card
- wire
- wire cutter-strippers

PART I: DETERMINING TRUTH TABLES FOR 4-, 6- and 8-NAND GATES

PROCEDURE:

1. Install the following cards in the brain frame.
    a. TT (input sockets at top)
    b. 4-NAND card
    c. 8-NAND card

IMPORTANT! REMEMBER TO INSTALL ALL GATE CARDS WITH "+" AT THE RIGHT.

2. Connect the four TT leads on the left to the four inputs of one of the 4-NAND gates.

3. Connect T to X on the BIP. Then connect the BIP to the brain frame, by connecting W to the upper-left corner socket of the 4-NAND card and S to the upper-right corner socket of the card.

4. Plug in the BIP.

5. Experiment with various TT inputs to check the behavior of the 4-NAND gate. Find out what you have to do to get the diode light to go out (i.e., to get an output of 0). Record your results.

6. Disconnect the 4-NAND card from the TT card and connect all eight of the TT leads to the eight inputs of the 8-NAND card. Repeat Step 5 for this gate. Record your results.

7. The 8-NAND gate can be converted to a 6-NAND gate and used for a circuit with six finding inputs. To do this, first disconnect two of the leads running

from the TT card to the 8-NAND input sockets (Figure 2A). You now have six inputs feeding into the 8-NAND gate. Now use two wires to connect the input sockets of the 8-NAND card as shown in Figure 2B. The three inputs on the right side of the card are now electrically the same. This is the same technique you used in Laboratory Activity 11 to convert a 2-NAND gate to an INVERT gate.

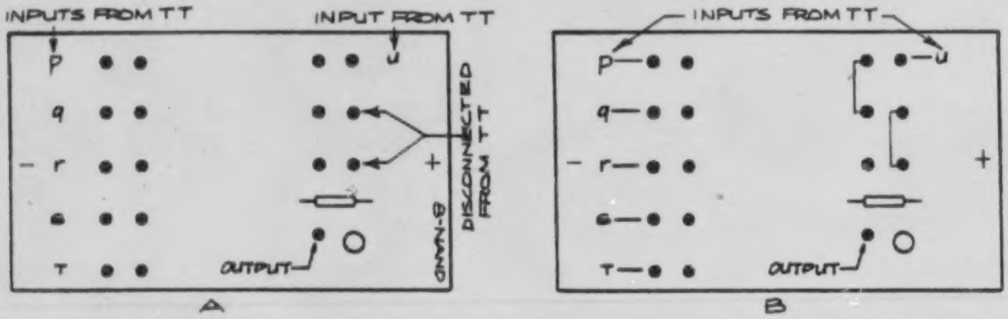

INPUTS FROM TT
INPUT FROM TT
p
q
r
s
t
u
−
+
OUTPUT
8-NAND
DISCONNECTED FROM TT
A
INPUTS FROM TT
p
q
r
s
t
u
−
+
OUTPUT
B

FIGURE 2: Converting an 8-NAND card to a 6-NAND card.

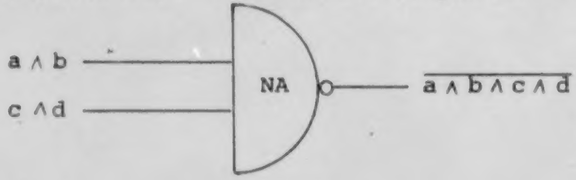
8. Check the behavior of the 6-NAND gate by repeating Step 5. Record your results.

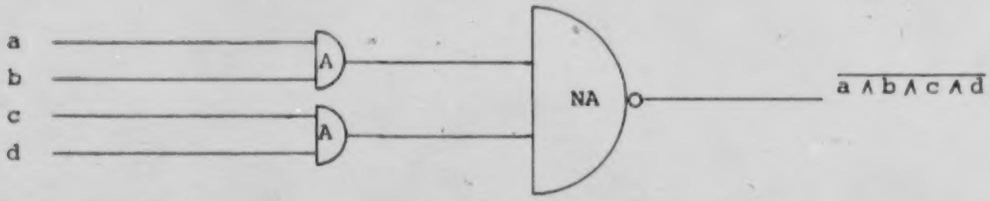
PART II: EQUIVALENT CIRCUITS FOR 4-NAND AND 6-NAND GATES

In designing your brain-disease computer you may end up with a diagram requiring a 4-NAND or 6-NAND gate, only to find that you have already used up your supply of these gates elsewhere. In this case, you will have to design equivalent circuits using gates with fewer inputs. Here are a few examples of how this is done. You will find the truth tables and switching functions given at the beginning of the Introduction useful.

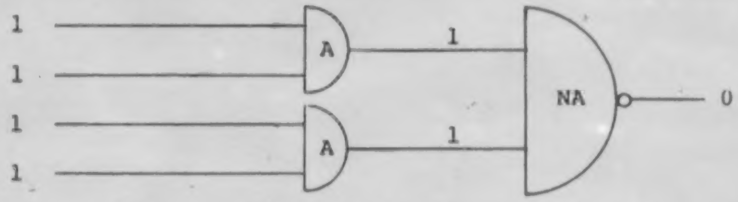
EXAMPLE 1: Suppose that you have four findings that you want to route through a 4-NAND gate, but don't have a 4-NAND gate. Fortunately, you have the following other gates available to you: two 2-AND gates and one 2-NAND gate. Draw a diagram showing how you would connect the above gates to give a circuit equivalent to a 4-NAND gate.

SOLUTION: The switching function for a 4-NAND gate is $\overline{a \wedge b \wedge c \wedge d}$. If we insert parentheses around $a \wedge b$ and $c \wedge d$ we get $\overline{(a \wedge b) \wedge (c \wedge d)}$. This is the output of a 2-NAND gate with inputs of $a \wedge b$ and $c \wedge d$. We can now easily complete the circuit using the two 2-AND gates.

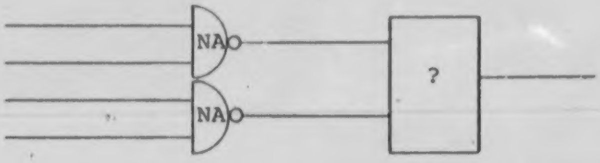

a ∧ b
c ∧d
NA
$\overline{a \wedge b \wedge c \wedge d}$


a
b
c
d
A
A
NA
$\overline{a \wedge b \wedge c \wedge d}$

We now check our circuit design. Looking at the truth table for a 4-NAND gate we see that the output is 0 only when the inputs are all 1's. The circuit above must behave the same way. So we start with an output of 0 and work back to the inputs to see if they are all 1's. The result is the following.

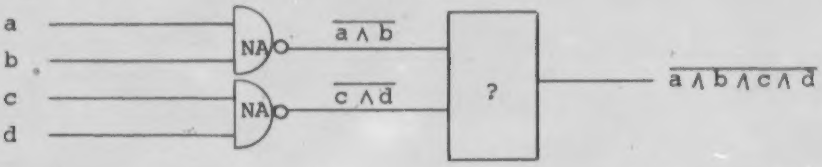

1
1
1
1
A
A
1
1
NA
0

EXAMPLE 2: Suppose that you have two 2-NAND gates that you are using for four finding inputs, as shown below. You also have a 2-AND, a 2-NOR and a 2-OR gate. Which of these would you need to connect to the two 2-NAND's to obtain an output that would correspond to that of a 4-NAND gate?



SOLUTION:

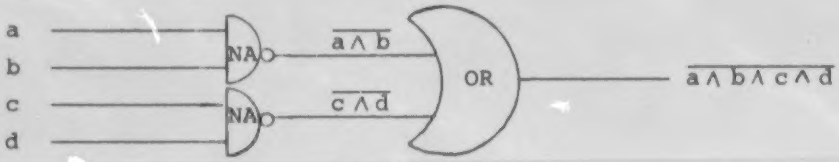
The switching function for a 4-NAND gate is $a \wedge b \wedge c \wedge d$. We fill in all the switching functions we know on the diagram.


a
b
c
d
NA
NA
$\overline{a \wedge b}$
$\overline{c \wedge d}$
?
$\overline{a \wedge b \wedge c \wedge d}$

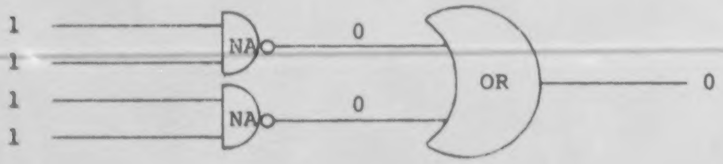
We now use De Morgan's law to put the output switching function in another form.

$$\overline{a \wedge b \wedge c \wedge d} = \overline{(a \wedge b)} \vee \overline{(c \wedge d)}$$

On the right the expressions $\overline{a \wedge b}$ and $\overline{c \wedge d}$ are joined by an "or". Therefore the missing gate is an OR gate.


a
b
c
d
NA
NA
$\overline{a \wedge b}$
$\overline{c \wedge d}$
OR
$\overline{a \wedge b \wedge c \wedge d}$

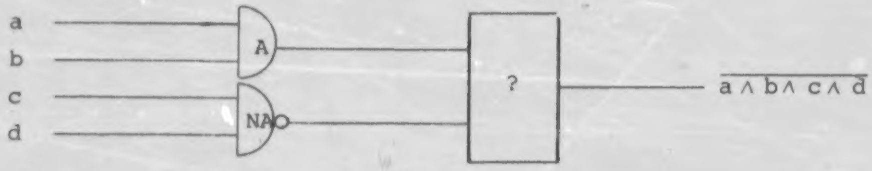
Finally we check the circuit. Again the output should be 0 only when all the inputs are 1.


1
1
1
1
NA
NA
0
0
OR
0

PROCEDURE:

There are three problems below that deal with constructing circuits equivalent to either a 4-NAND or a 6-NAND gate. First solve each problem on paper, i.e., draw the circuit that provides the correct answer and check it. After you have done this connect up the appropriate cards on the brain frame and test your solution. If you don't remember how gates respond to specific input combinations refer back to the truth tables in Laboratory Activity 10.

PROBLEM 1: You are provided with the initial circuit shown below. In addition you are provided with a 2-NAND, 2-NOR, 2-AND and an INVERT gate card. How could you use one or more of these cards to complete the circuit in such a way that it gives the same output as a 4-NAND gate? (You will need to use the fact that $\overline{a \wedge b \wedge c \wedge d} = \overline{(a \wedge b)} \vee \overline{(c \wedge d)}$.)



PROBLEM 2: You are given a 4-NAND gate, a 2-NAND gate and a 2-OR gate. How can you combine them to form a circuit equivalent to a 6-NAND gate? (Hint: the switching function for a 6-NAND gate is $\overline{a \wedge b \wedge c \wedge d \wedge e \wedge f}$. By De Morgan's law this is equivalent to $\overline{(a \wedge b \wedge c \wedge d)} \vee \overline{(e \wedge f)}$.)

PROBLEM 3: You are given three 2-NAND and two 2-OR gates. How might you combine them to form a circuit equivalent to a 6-NAND gate?

ACTIVITY 13A: CIRCUITRY FOR THE DIAGNOSTIC COMPUTER

INTRODUCTION:

In preceding activities you have gained experience with the logic gates that you will use to construct a diagnostic computer. You have seen how to progress from truth tables of findings and diagnoses to logic statements, to circuitry design and finally to actual construction of a simple diagnostic computer. It is now time for you to design the circuitry that will make up a computer for diagnosing brain diseases. To do this refer to the simplified truth table you arrived at in Activity 12A. You may also need to refer to the truth tables for the various logic gates in Laboratory Activities 10 and 12B.

A list of all the logic gates that will be available to you is given below.

three INV cards (18 gates)
2-AND card (4 gates)
2-OR card (4 gates)
2-NOR card (4 gates)
two 2-NAND cards (8 gates)
two 4-NAND cards (4 gates)
8-NAND card (1 gate)

PROCEDURE:

1. Using the simplified truth table you arrived at in Activity 12A, write the logic statement that gives a possible diagnosis for each disease. For example, a sample truth table for hepatitis is shown in the following table.

FINDINGS							POSSIBLE DIAGNOSIS
a - high fever	b - chills	c - general aching	d - cough	e - loss of appetite	f - sudden onset	g - abdominal pain	
0	1/0	1	0	1	1/0	1/0	hepatitis

The logic statement for hepatitis is $\bar{a} \wedge c \wedge \bar{d} \wedge e$. The remaining findings are disregarded because they may be present or absent in hepatitis.

2. Consider one disease at a time, starting with those having the largest number of inputs in their statements. Design a circuit for each statement. Remember to include the INVERT diagnosis gate. A possible circuit design for the opposite example of hepatitis is shown in Figure 1.

Important: As you design circuits for the various diseases, be sure to pay attention to the number of each kind of gate you use. Remember, you have a limited quantity, and may need to use alternate circuit designs for some diseases.

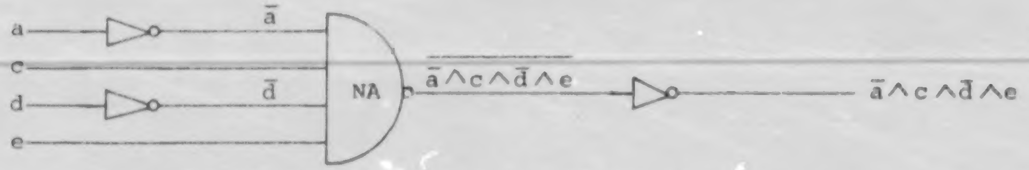

a
c
d
e
$\bar{a}$
$\bar{d}$
NA
$\overline{\bar{a} \wedge c \wedge \bar{d} \wedge e}$
$\bar{a} \wedge c \wedge \bar{d} \wedge e$

FIGURE 1: Circuit for hepatitis diagnosis.

For example, if the 4-NAND gate shown in the Figure 1 example is not available, you can replace it with the equivalent circuit shown in Example 1 of Laboratory Activity 12. The result is shown in Figure 2.

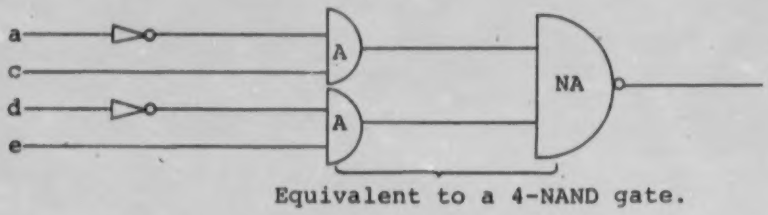

a
c
d
e
A
A
NA
Equivalent to a 4-NAND gate.

FIGURE 2: An alternate circuit for hepatitis diagnosis.

3. After you have diagrammed the circuits for each separate disease, connect them up to a master diagram like that in Figure 3.

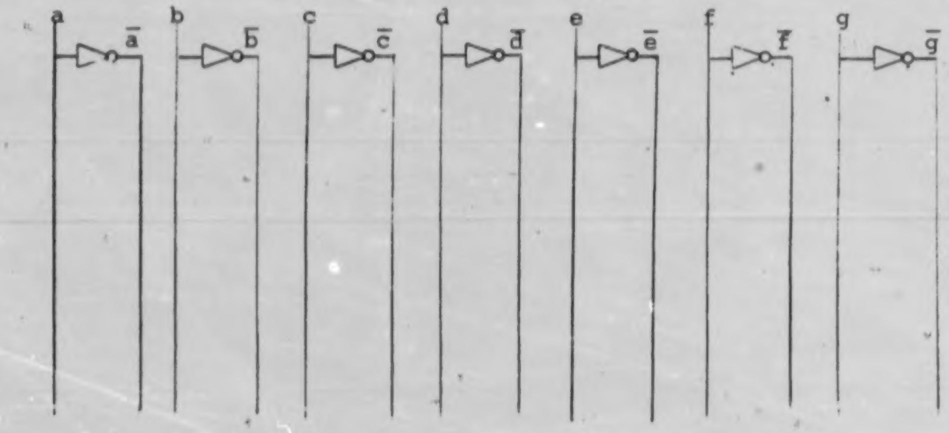

a
$\bar{a}$
b
$\bar{b}$
c
$\bar{c}$
d
$\bar{d}$
e
$\bar{e}$
f
$\bar{f}$
g
$\bar{g}$

FIGURE 3: Input diagram for findings.

Notice that seven inputs (a through g) are labeled at the top and there are two lines associated with each input. For example, under "a," one line symbolizes an input of a, while the other one, which has been run through an INVERT gate, symbolizes $\bar{a}$. When drawing your circuit diagrams, be sure to run lines from the various gates to the correct finding inputs. (If you aren't careful, you could connect a line that required an input of $\bar{a}$ to the "a" line.)

Figure 4 shows an example of how to draw in the circuit of Figure 1, based on the example of hepatitis.

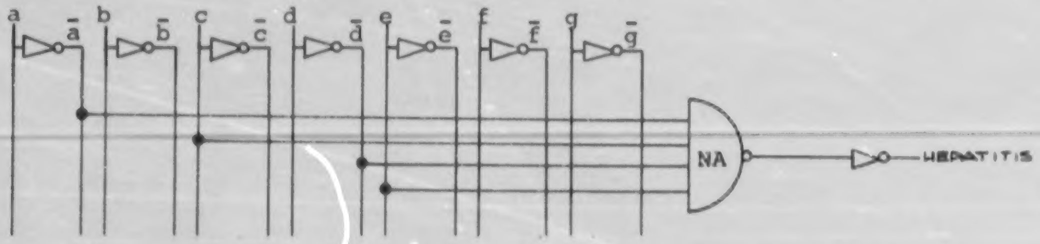

a
$\bar{a}$
b
$\bar{b}$
c
$\bar{c}$
d
$\bar{d}$
e
$\bar{e}$
f
$\bar{f}$
g
$\bar{g}$
NA
HEPATITIS

FIGURE 4: Connecting the hepatitis circuit to the finding inputs diagram.

Since the connecting lines cross many finding input lines, we designate the desired connection points with dots.

Construct a combined circuit diagram by connecting your brain-disease circuits to an inputs diagram like that in Figure 4.

4. When you have completed the combined circuit diagram for all the diseases make the following checks.

   a. Are all five diseases included?
   b. Are all the finding input connections to the gates complete?
   c. Are the finding input connections made to the correct finding input lines on the diagram (i.e., a or $\bar{a}$, b or $\bar{b}$, etc.)?
   d. Do you have enough gates available to construct the circuits designed?
   e. Do all circuits lead through a final INV gate?

LABORATORY ACTIVITY 13B: CONSTRUCTING THE BRAIN-DISEASE COMPUTER

INTRODUCTION:

In Activity 13A, you designed the circuitry for your brain-disease computer. In this activity you will construct the computer by installing the appropriate gate cards on the brain frame and making the necessary connections. When you have finished, you should have a computer that will tell you which (if any) of the five brain diseases (epilepsy, cerebral thrombosis, cerebral hemmorrhage, multiple sclerosis and brain tumor) are possible diagnoses when a given set of findings are present.

The procedure to be followed in connecting the computer is the same as in Laboratory Activity 11, in which you constructed a simpler computer for diagnosing a cold and/or strep throat. The main differences are that you will be connecting five separate circuits instead of two and you will be dealing with more than three findings.

MATERIALS:

BIP and brain frame
three INV cards (18 gates)
2-AND card (4 gates)
2-OR card (4 gates)
2-NOR card (4 gates)
two 2-NAND cards (8 gates)
two 4-NAND cards (4 gates)
8-NAND card (1 gate)
TRUTH TABLE card
wire
wire cutter-strippers

PROCEDURE:

1. Install the TT card and all the gate cards you will need on the brain frame. Refer to your circuit diagrams from Activity 13A.

2. Make a map of the brain-frame set-up like the one shown at the end of this procedure. All the logic gates you will use should be included. You should label your map to show the following:

a. the positions of the various findings on the TT card,
b. the positions of the brain diseases on the diagnosis INVERT card,
c. information on which gates on each card are associated with which disease circuit,
d. information on which inputs on each gate you will use for which findings.

IMPORTANT: The map shown at the end of this procedure is only a sample map. Your map will be labeled differently, depending upon how you have designed the circuitry.

3. Connect as many TT leads as you have findings to the input sockets of separate INVERT gates. (This will require two INVERT cards if you have more than six findings.) Label, on your map, the input for each INVERT gate you have used. From these "finding" INVERT gates you now have available both p (from the other input socket) and $\bar{p}$ (from the output socket) for each of your findings.

4. Complete the circuit for epilepsy all the way to the diagnosis card.

5. Connect T to X on the BIP. Then connect the BIP to the brain frame by connecting the W lead to the upper-left terminal on one of the gate cards and the S lead to the upper-right terminal on the same card.

6. Plug in the BIP.

7. Test your "epilepsy" circuit by connecting, on the TT card, an input of 1 for every finding that must be present and an input of 0 for every finding that can't be present. If the "epilepsy" LED on the diagnosis card does not come on, recheck your wiring.

8. Try a few combinations other than the one tested in Step 7. In each case the LED should not light up.

9. Complete the circuit for each of the remaining four diseases in turn. The circuits involving 8-input and 4-input gates should be done first. Test each disease circuit before going on to the next. As you proceed, it will become more complicated to find an available socket for the particular finding input you need. In order to find an available socket use the following procedure.

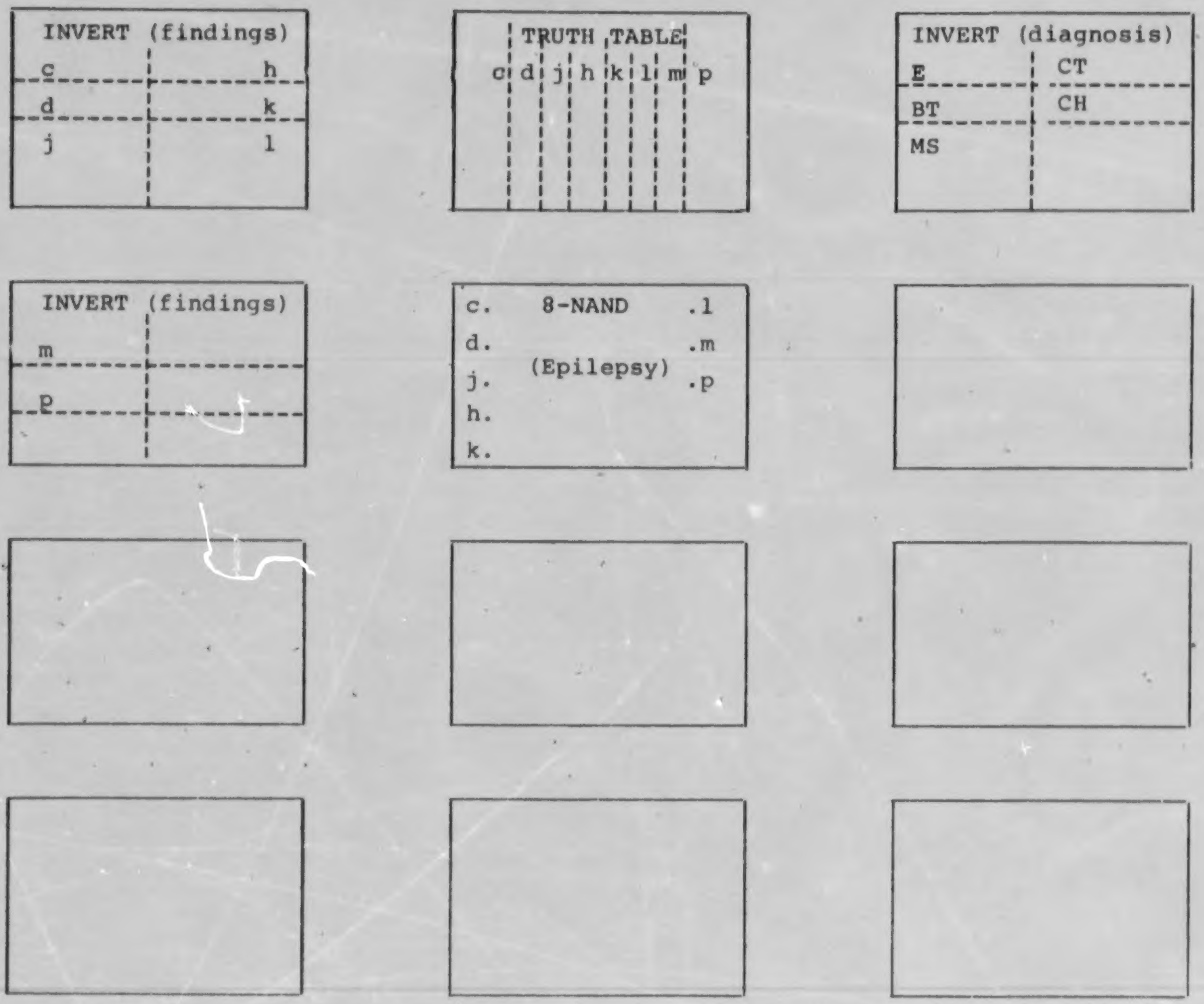
a. Suppose you need an input of $\bar{p}$. Is the output socket of the "finding" INVERT card free? If so use it. If not, follow the wire leaving it to the socket where the other end is connected.
b. You are now at the input socket for a gate. There are always two input sockets which are electrically the same. Is the other input socket free? If so, use it. If not, follow the wire from that second socket to its end.
c. You are now at the input socket for another gate. You can now repeat Step b, checking the other electrically equivalent input socket. Continue this process of following wires until you find a free socket.

10. Check out the completed computer by trying various combinations of findings. Use your truth tables to try sets of findings that should produce more than one disease possibility. Try combinations of findings that should produce no disease. Record your results in a truth table like the one on the following page.

FINDINGS

c	d	j	h	k	l	m	p	DISEASE POSSIBILITIES
1	0	1	1	0	0	1	0	none

SAMPLE BRAIN-FRAME MAP


INVERT (findings)
c
h
d
k
j
l
TRUTH TABLE
c d j h k l m p
INVERT (diagnosis)
E
CT
BT
CH
MS
INVERT (findings)
m
p
c.
8-NAND
.l
d.
.m
(Epilepsy)
j.
.p
h.
k.

E = epilepsy
CT = cerebral thrombosis
BT = brain tumor
CH = cerebral hemorrhage
MS = multiple sclerosis

LABORATORY ACTIVITY 14: PREPARING DRUGS FROM PLANT SOURCES

INTRODUCTION:

Many medical drugs are made from natural products. In this activity you will prepare some common medications from plant sources, much as a pharmacist would prepare them. The activity is in four parts. In each part you will prepare a different drug.

Note: in the activity there are a number of terms that are frequently used by pharmacists and physicians. For your reference, these terms have been compiled in a list at the end of the activity.

PART I: PREPARATION OF WILD-CHERRY SYRUP

INTRODUCTION:

Wild-cherry syrup may be used in either of two ways. It is used as a mild astringent (an agent that causes contraction or shrinkage of soft tissues) and expectorant (an agent that promotes discharge of mucus from the respiratory tract). Wild-cherry syrup is more commonly used as a solvent and flavoring agent for drugs that can be dissolved in the syrup and taken orally by patients who have trouble taking pills. Flavored drugs are often prescribed for young children.

Wild-cherry powder is the ground-up bark of a type of cherry tree that grows in eastern and central North America. The powder contains tannic acid, which is an astringent found in tea and in other plant materials. It also contains mandelonitrile glucoside (Figure 1) and an enzyme mixture known as emulsin.

During preparation of the syrup you will soak the wild-cherry powder in cold water. While it is soaking, the emulsin hydrolyzes the mandelonitrile glucoside into three smaller products: (1) glucose, (2) benzaldehyde (which gives wild-cherry syrup its characteristic flavor and odor) and (3) a very small amount of hydrogen cyanide (which would be poisonous at higher concentrations).

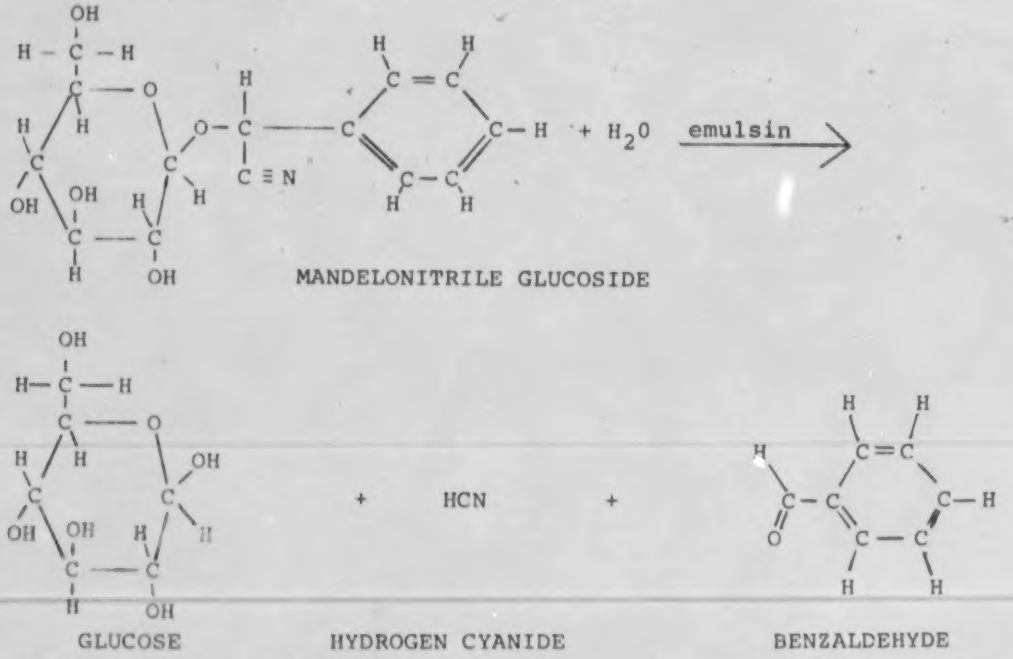


FIGURE 1: Hydrolysis of mandelonitrile glucoside.

MATERIALS:

- materials for percolator set-up:
    - acrylic column
    - purified sand
    - cotton
    - rubber stopper, one-hole, #4
    - rubber stopper, solid, #4
    - pinch clamp (or screw clamp)
    - rubber tubing
    - glass tubing
    - ring stand and clamp
    - filter paper
- glass stirring rod
- 2 beakers, 50-ml
- pipet, 10-ml
- sucrose (table sugar)
- balance
- wild-cherry powder
- glycerin

PROCEDURE:

1. Construct a percolator as shown in Figure 2. ("Percolation" is the process of passing a liquid through a porous solid.) The purified sand is used to hold the cotton in place and to provide a firm, porous support for the filter paper. Be sure to insert the filter paper so that it fits snugly against the sides of the column. Otherwise some liquid may seep around instead of through the paper, resulting in improper filtration. Close the pinch clamp.

2. Moisten 3 ± .2 g of wild-cherry powder with approximately 2 ml of tap water in a beaker. Then transfer the powder into the percolator.

3. Rinse the beaker with 5 to 10 ml water. Use this water to transfer any remaining powder to the column. There should be a few ml of water above the powder.

4. Stopper the top of the column and let the powder soak for 30 to 60 minutes. This soaking is called "maceration." During maceration the mandelonitrile glucoside in the wild-cherry powder is hydrolyzed enzymatically. If you unstopper the top of the column after a half-hour or more of maceration, you should be able to detect the familiar wild-cherry odor of benzaldehyde, one of the hydrolysis products. While the maceration is taking place, go on to Part II of the activity.

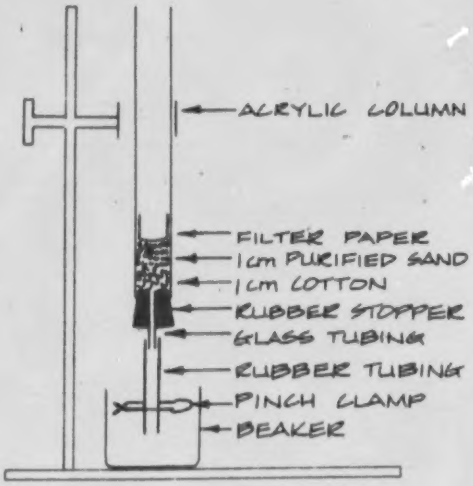


FIGURE 2: A percolator set-up.

5. When the maceration is complete, remove the upper stopper, release the pinch clamp and allow the percolation to proceed. Collect 8 ± 2 ml of percolate in a beaker, adding additional water to the column if needed.

6. Add 13.5 ± .5 g sucrose to the percolate and dissolve the sugar by stirring. The sucrose is added for flavor. It is dissolved by stirring rather than by heating because two of the compounds in the syrup, benzaldehyde and hydrogen cyanide, can be readily vaporized and driven off by heat.

7. Add 3 ± .5 ml glycerin with a pipet. Glycerin is added to keep the tannic acid dissolved in the syrup. Tannic acid is poorly soluble in water and precipitates if glycerin is not added.

8. Add enough water to make about 20 ml of syrup. At this point a pharmacist would strain the syrup to remove any particles that had escaped from the percolator.

9. Observe and smell the syrup. Do not put any of it in your mouth. Record your observations on a data sheet.

PART II: PREPARING CÁSCARA-SAGRADA INFUSION

INTRODUCTION:

Cáscara sagrada is the dried, powdered bark of cascara buckthorn, a tree that grows on the Pacific Coast of North America. The California Indians used a preparation of this bark as a cathartic (a drug that cuases people to defecate), and the drug is still used for that purpose. The name of the drug, cáscara sagrada, means "sacred bark" in Spanish.

The main active ingredient in cáscara sagrada is a complex organic compound called cascarin, or frangulin. This substance in itself does not have an effect on the body. However, when it reaches the bowel it is broken down, probably with the aid of enzymes produced by intestinal bacteria. One of the breakdown products is a compound called emodin. This substance, also found in rhubarb, promotes defecation by stimulating peristalsis in the large intestine. Since the drug does not become active until it is broken down in the bowel, it does not begin to take effect until six to eight hours after it is ingested.

Cáscara sagrada is most commonly prepared by treating it before percolation to remove some of its bitter flavor and then mixing it after percolation with a preparation of dried licorice root. The licorice is added to mask the bitter flavor of the drug.

In this part of the activity, you will prepare an infusion of cáscara sagrada. An infusion is a preparation made by macerating or percolating a substance with hot water.

MATERIALS:

coarse cáscara-sagrada powder
tea strainer
2 beakers, 150-ml
cover for beaker (watch glass or Petri-dish lid)
gas burner
ring stand
wire gauze
glass stirring rod
tongs (or asbestos gloves or pot holder)
balance

PROCEDURE:

1. Place 1 ± .1 g of cáscara sagrada in a beaker. Add a few drops of cold water and mix well to moisten the powder.

2. Measure 20 ml of water into the other beaker and heat it until the water begins to boil.

3. When the water in the beaker boils, turn off the burner and pour the water carefully into the beaker that has the powder in it. (Use tongs or an asbestos glove or a pot holder to grip the beaker.) Cover the beaker (with a watch glass or Petri-dish lid) and allow the drug to macerate for 15 minutes.

4. After maceration, pour the preparation through a fine tea strainer into a clean beaker.

5. Pour enough cold water through the strainer and into the beaker to bring the volume of product up to approximately 20 ml.

6. Record your observations. Do not put any of the infusion in your mouth.

PART III: PREPARATION OF WITCH-HAZEL-LEAF EXTRACT

INTRODUCTION:

Witch hazel is the common name for a shrub, Hamamelis, which is widely distributed in Canada and the eastern United States. Witch-hazel preparations are used mainly as astringents, their active ingredient being hamamelitannin, a compound similar to tannic acid. These preparations are used on bruises, on insect bites and stings, and on sunburn and other burns. The American Indians used a witch-hazel preparation as an invigorating rub for muscular soreness after athletic contests.

In this part of the activity, you will prepare an extract of witch-hazel leaf. An extract is a preparation, usually in concentrated form, obtained by treating plant or animal tissue with a solvent to remove desired components of the tissue.

MATERIALS:

- percolator set-up (from Part I)
- 2 beakers, 50-ml
- 2 pipets, 10-ml
- glass stirring rod
- glycerin
- ethyl alcohol, 95%
- witch-hazel leaf (a coarse powder)
- balance

PROCEDURE:

1. Construct a percolator as in Part I, Step 1. (Note: the percolator used in Part I must be rinsed and repacked with fresh sand, cotton and filter paper.)

2. Pipet 9 ± 1 ml of ethyl alcohol and 1 ± .1 ml of glycerin into a beaker. Water is not used for witch-hazel preparations because the tannic acid in the powder is much more soluble in alcohol and glycerin than in water.

3. Place 10 ± .1 g of the witch-hazel powder in another beaker, and add about 6 ml of the solvent (the alcohol-glycerin mixture). Mix well to dampen the powder.

4. Let the dampened powder stand for about 15 minutes. While the powder is macerating, proceed to Part IV.

5. When 15 minutes are up, rinse the beaker with the remainder of the solvent. Add this suspension to the percolator.

6. Stopper the top of the column and let the powder macerate for one to two days.

7. When the maceration is complete, remove the rubber stopper from the top of the percolator. Open the pinch clamp and let the percolation proceed into a 50-ml beaker.

8. When there is no more solvent above the powder, add another 5 to 10 ml of ethyl alcohol. Allow the percolation to proceed until you have collected 8 to 12 ml of percolate.

9. Record your observations of the extract. How does the extract look? Describe its odor. Place a few drops on your hand and rub the extract in. How does it feel?

PART IV: PREPARING SPIRITS OF CAMPHOR

INTRODUCTION:

Camphor is a complex organic compound taken from the wood and bark of the camphor tree, which is native to several parts of Asia and is widespread in Taiwan and Japan. Camphor has long been used in Chinese medicine. It has some uses in modern medicine, but most camphor sold in this country is manufactured synthetically rather than being extracted from the camphor tree.

Camphor has a variety of medical uses. Applied to the skin, it is a counter-irritant, causing inflammation of the skin and thus reducing inflammation of nearby internal parts (e.g., a sprained ankle). It is also a mild local anesthetic, and may produce a feeling of numbness on the skin where it is applied. In addition, it produces a feeling of coolness on the skin (and, if inhaled, on mucous membranes) by stimulating the nerve endings that are sensitive to cold. Finally, camphor is a mild antiseptic.

Although camphor is no longer used internally, it was once used as a heart and circulatory stimulant (it mildly stimulates the central nervous system), a carminative (an agent that promotes expulsion of gas from the digestive system and thus helps to relieve intestinal cramps) and an expectorant.

"Spirits" may be generally defined as a solution of a volatile substance in alcohol. (A volatile substance is one that readily vaporizes, such as camphor.) The alcohol in spirits evaporates quickly, and spirits must be kept in well-stoppered bottles. They must also be kept away from heat and light to prevent chemical changes in the substance dissolved in the alcohol.

MATERIALS:

camphor
ethyl alcohol, 95%
beaker, 50-ml
pipet, 10-ml
glass stirring rod
balance

PROCEDURE:

1. Place 1 ± .1 g camphor in a beaker.
2. Add 9 ± 1 ml of ethyl alcohol to the beaker. Stir to dissolve the camphor.
3. Record observations of your product. Describe its odor. Rub a few drops on the back of your hand. How does it feel?

DISCUSSION QUESTIONS:

1. Have you ever ingested wild-cherry syrup? If so, for what purpose?
2. Have you ever used a witch-hazel preparation? If so, for what purpose?
3. Why must spirits be bottled and capped?
4. What infusions have you used? (Hint: not all infusions are medicines.)
5. Why do you suppose cáscara sagrada can be macerated in boiling water, while wild-cherry bark cannot?

VOCABULARY:

astringent (a-STRIN-junt)--an agent that causes contraction or shrinkage of soft tissues--used for treating bruises, burns, insect bites, etc.

carminative (kahr-MIN-uh-tiv)--an agent that promotes expulsion of gas from the digestive system.

cathartic (kuh-THAHR-tick)--an agent that promotes defecation.

counterirritant (KOWN-tur-EAR-ih-tunt)--an agent that causes inflammation of the skin, thus reducing more deep-seated inflammation.

expectorant (eck-SPECK-tow-runt)--an agent that promotes discharge of mucus from the respiratory tract.

extract (ECK-stract)--a preparation, usually in concentrated form, obtained by treating plant or animal tissue with a solvent to remove desired tissue components.

infusion (in-FEW-zhun)--a preparation made by macerating or percolating a substance with hot water.

maceration (MASS-ur-A-shun)--the process of soaking plant or animal tissue in a liquid.

percolation (PUHR-ko-LAY-shun)--the process of passing a solvent through a column containing a solid substance, thereby removing soluble constituents of the substance.

spirits--a solution of a volatile substance in alcohol.

LABORATORY ACTIVITY 16: MICROORGANISMS FROM THE SOIL

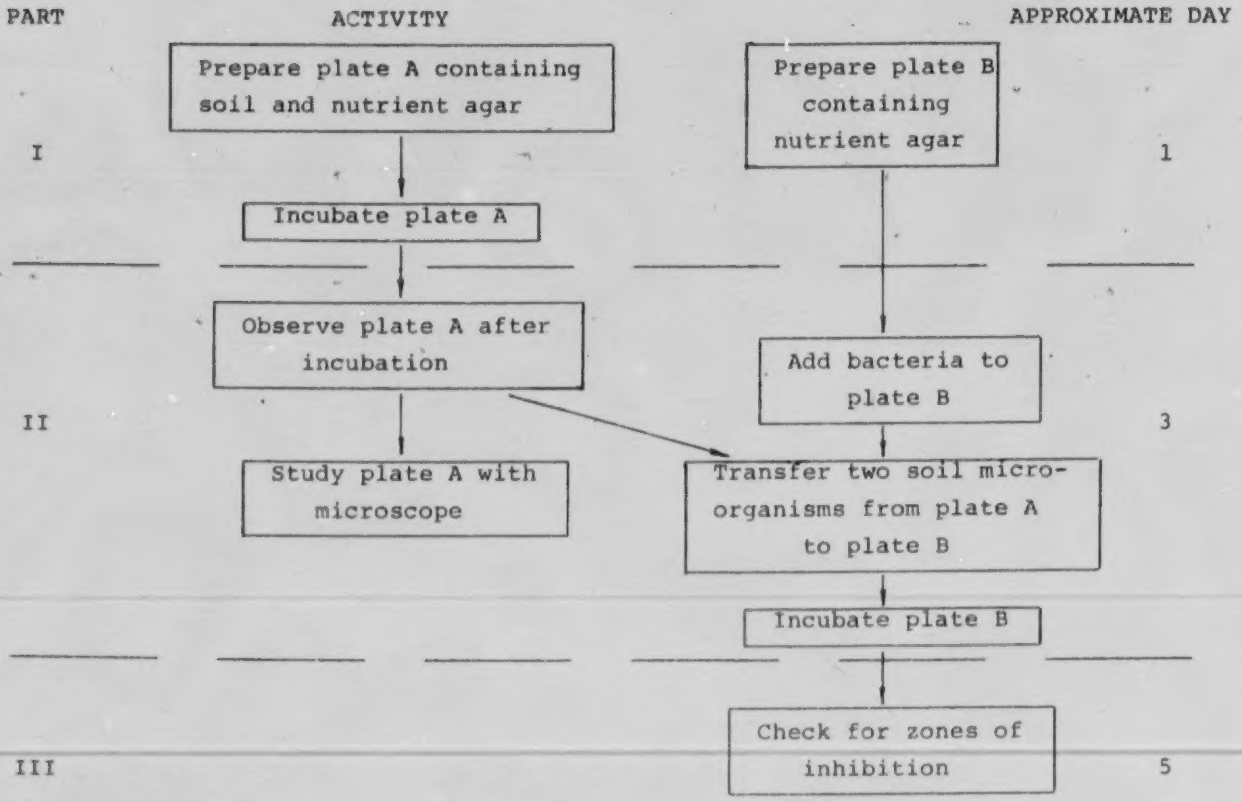
GENERAL INTRODUCTION:

A major research effort of drug companies is to identify new organisms from the soil--microscopic organisms, that is--bacteria and fungi. One could look elsewhere for these organisms, but soil is the main source because it is teeming with them.

Why do drug companies bother to do this? Because a few soil organisms produce antibiotics, substances that inhibit the growth of pathogens (organisms that cause disease). In this activity you will grow organisms from the soil and then perform tests to see whether they produce antibiotics.

There are three parts to the activity, as shown in the flow chart. In the first period you will place some soil on a nutrient agar plate, for many soil organisms grow well on this medium. In the second period, after the organisms have grown, you will select two different organisms and test them for antibiotic activity by adding them to bacteria. In the third period you will examine the bacteria to see how they have grown. If their growth has been inhibited near a soil organism, then one can conclude that the soil organism may be producing an antibiotic. The purpose of this activity is not only to try to locate antibiotic-producing microorganisms, but also to give you a chance to improve your microbiological techniques.

FLOW CHART


PART
ACTIVITY
APPROXIMATE DAY
Prepare plate A containing soil and nutrient agar
Prepare plate B containing nutrient agar
I
1
Incubate plate A
Observe plate A after incubation
Add bacteria to plate B
II
3
Study plate A with microscope
Transfer two soil microorganisms from plate A to plate B
Incubate plate B
Check for zones of inhibition
III
5

WARNING

In this and other activities you will be working with cultures of bacteria. Bacteria should always be treated with respect. While the bacteria that are provided are normally harmless, they can cause disease if they find their way to certain places in the body. For example, *E. coli*, a normally harmless and even useful bacterium found in human intestines can cause infections of the urinary bladder if it gets into the urinary tract. Therefore, care must be exercised even though infections from handling bacteria in the laboratory are rare.

It is important that you learn correct methods of handling bacteria while you are working with bacteria that are normally harmless. You will then be able to apply the same techniques if you work with pathogenic bacteria. This is important if you ever work in a medical laboratory.

The following precautions should be employed each time you work with bacteria.

1. Wash your hands thoroughly with soap and water before and after the laboratory activity.

2. When working with bacteria, do not eat any food, drink from laboratory glassware, or put fingers, pencils, etc., in your mouth. Keep all sources of bacteria away from open cuts or sores.

3. If a bacterial culture is spilled, notify your instructor immediately.

4. Discard all cultures, liquid wastes and media as directed by your instructor, and only in containers specified for this purpose. Sterilize all live cultures before disposal.

5. At the conclusion of the laboratory period, wash the top of the lab desk with disinfectant.

PART I: PLATING SOIL MICROORGANISMS

INTRODUCTION:

In this part you will melt two sterile tubes of nutrient agar (sterile means free of any microorganisms). To one, you will add some diluted soil sample. Then, you will pour the contents of each tube into a Petri dish to make agar plates. One plate will thus contain agar with soil, and the other will contain sterile agar.

In order to ensure that only microorganisms from the soil grow on the agar, we will use sterile technique. This technique prevents microorganisms from other sources, such as dust in the air, from getting into the agar.

MATERIALS:

- 2 capped test tubes containing sterile nutrient agar
- test tube, 16 x 125 mm
- 2 Petri dishes, sterile
- hot water bath
- germicide
- paper towels
- glass-marking pencil
- test-tube holder
- #4 or 5 stopper
- 250-ml Erlenmeyer flask
- 250-ml beaker
- test-tube rack
- scale
- thermometer
- 500- or 1000-ml beaker
- 1-ml pipet
- 10-ml pipet

PROCEDURE:

1. Clear away unnecessary papers and other items, and disinfect (clean) a large area of the table top around your work space by wiping it down with germicide solution. (This procedure wipes away dust that is on the table and also kills many bacteria. Dust kicked up from the table would contaminate the sterile agar when it is poured.)

2. Obtain two test tubes of sterile nutrient agar and melt the agar in a boiling water bath. (In boiling water, melting takes about five minutes.) Leave the caps on the test tubes to keep dust out.

3. While the agar is heating up, proceed to Step 6, but keep an eye on the agar. As soon as it melts completely, continue with Steps 4 and 5.

4. As soon as the agar is completely melted, remove the test tubes from the hot water bath with a test-tube holder. Obtain a 250-ml beaker half-full of water at a temperature of 45 to 50 °C. Place the melted agar tubes in the water bath without removing their caps. Allow the tubes to cool down to the same temperature as the water bath. This can be tested after about 5 minutes by rolling the tubes in the palms of your hands. They should feel approximately as warm as the surrounding water. Note: do not overcool, as the agar medium will resolidify and the tubes will have to be melted once again in a hot water bath.

5. While the tubes of nutrient agar are cooling, place two sterile Petri dishes on the table. Do not open them. Label one Petri dish "A" and the other "B."

6. Dilution of the soil sample is necessary because soil is so rich in microorganisms that if placed in agar directly, there would be so much growth that it would be impossible to distinguish one kind of microorganism from another. Many colonies of microorganisms would overlap. Dilute the soil as follows.

Suspend 2.0 ± 0.1 g of soil in 200 ± 5 ml of tap water in a 250-ml Erlenmeyer flask. Stopper and shake this suspension very thoroughly. This dilutes your soil by a factor of 100.

7. Now you will dilute the soil suspension even more to arrive at a final soil dilution factor of 1,000. Do this by taking the 100-fold dilution and diluting it by a factor of 10 (100 x 10 = 1,000) as follows. Obtain a 1- and a 10-ml pipet and a test tube. Label the test tube "S." Pipet 9.0 ± 0.1 ml of water into test

tube S. Shake the suspension in the Erlenmeyer flask and transfer 1.0 ± .05 ml of the well-mixed suspension into tube S. Shake tube S thoroughly. You now have a soil sample diluted 1,000 times.

8. If you have not already done so, complete Steps 4 and 5.

9. As soon as the agar tubes have reached the proper temperature, you are ready to proceed. Label one agar tube "A" and the other "B." Transfer 1.0 ± .2 ml of soil sample from tube S to tube A. Remove the cap on tube A only when making the transfer, don't put the cap on the desk, and put the cap back on as soon as possible. This procedure minimizes the amount of dust that gets into the agar and minimizes the chance of contamination. Leave tube B alone.

Rapidly rotate tube A between the palms of your hands. This distributes the soil evenly throughout the agar.

10. Now pour the agar in tube A into Petri dish A. To do this, remove the cap from tube A, raise the lid of Petri dish A slightly (Figure 1) and pour the contents of the tube into the sterile Petri dish. (To keep dust out, do not remove the Petri-dish lid completely when pouring agar into the dish.) Replace the Petri lid immediately.

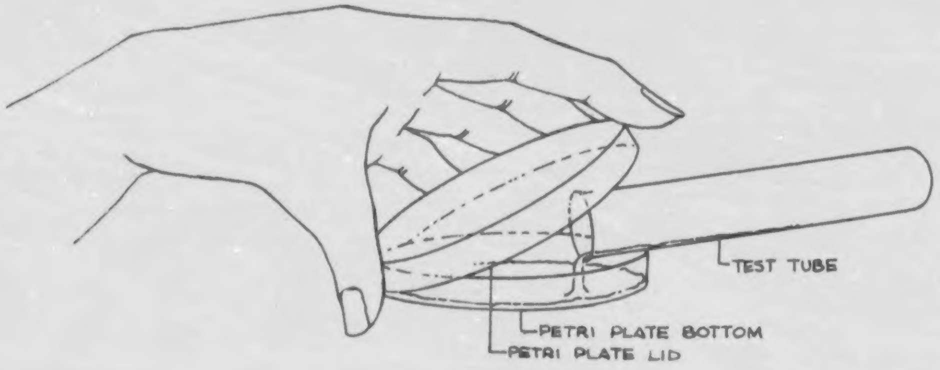


FIGURE 1: How to pour agar.

Allow about 15 minutes for the agar in the Petri dish to harden and cool. Do not move the Petri dish while it is cooling; moving it can make the agar uneven or lumpy.

11. Transfer the agar in test tube B into Petri dish B, using the same technique.

12. After 15 minutes, label Petri dish A "soil sample" and put your initials on both Petri dishes. Place them in a designated storage place at room temperature for a day or more. Incubate the Petri dishes upside down so water drops won't fall on the agar and disrupt the growth.

PART II: OBSERVING THE SOIL SAMPLE

INTRODUCTION:

In Part I, you inoculated agar with a soil sample. Now you will observe the organisms that have grown on the agar plate. You will also pick out and test two of the organisms to see whether they can inhibit the growth of bacteria. This is done by spreading bacteria over the surface of another agar plate and then adding the organisms from the soil. You will then incubate the plate to see whether the bacteria fail to grow near the organisms from the soil. Review the flow chart before proceeding.

MATERIALS:

tube with bacterial suspension
agar plates A and B from Part I
inoculating loop
germicide
packets of sterile cotton balls, wrapped in aluminum foil
alcohol, with cups or small beakers for distribution
aluminum foil, for disposing of used cotton balls
glass-marking pencil
forceps
gas burner

PROCEDURE:

1. Clear the work table and wipe it down with germicide solution.

2. Select a tube of bacterial suspension.

3. Obtain plates A and B prepared in Part I. Observe the growth on the plate marked "soil sample." Two kinds of organisms should be visible on the surface: bacteria and fungi. Fungi consist of many delicate thread-like strands. They are often markedly elevated above the surface of the agar. Soil bacteria, on the other hand, are usually solid, round masses, often with a shiny, white or yellow appearance. Each round mass of bacteria on the surface of the agar is a colony. Bacterial colonies are usually no more than 3 mm across (after 24 hours of incubation). (When a single bacterium lands in the agar it multiplies until it forms a visible mass--a colony.) Fungal colonies, on the other hand, may be 10 mm across or larger.

4. There are colonies growing inside the agar, and one cannot tell whether these are bacteria or fungi. Estimate the total number of colonies in the plate, including both those on the surface and those inside the agar. (1) Estimate the number of bacterial and the number of fungal colonies on the surface of the agar. (2) Which are in greater number on the surface, the bacterial or fungal colonies? (3) Do your estimates suggest that the number of microorganisms in soil is hundreds per ml of soil, thousands per ml of soil, hundreds of thousands per ml of soil, or more? (4) (Hint: assume that each colony arose from one microbe and also remember that you diluted the soil in water 1,000 times before putting 1 ml of it in the agar.)

5. Select any two colonies to test for antibacterial activity. You may choose two colonies of bacteria, two of fungi, or one of each. Use a glass-marking pencil to mark the underside of the Petri plate at the place where each colony you select

is located: draw a circle around each colony. Why is the circle drawn on the underside and not on the lid? (5) Write a description of each colony selected.

6. It will be necessary to have the following items readily available and conveniently arranged at your work table.

aluminum foil to put used cotton into
packet of sterile cotton balls,
  wrapped in aluminum foil
forceps
beaker or cup with alcohol
gas burner
agar plate

7. Carefully open the packet of sterile cotton balls. Do not touch the cotton with your fingers, to avoid contaminating the cotton. Expose the cotton balls just enough to be able to pick them up with the forceps, but don't pick them up yet.

8. Sterilize the end of a forceps by dipping the tip into alcohol and then touching the tip to a gas flame. Allow the alcohol to burn off. Caution! Fire hazard! Don't let the alcohol drip.

9. Pick up one cotton ball with the forceps. Holding the cotton with the forceps, remove the cap from the test tube containing bacteria and dip the cotton into the bacterial broth, letting the broth soak in. Don't let go of the cotton. (If necessary, tilt the tube without spilling it.) Withdraw the cotton, allow it to drip into the tube, and replace the cap.

10. Raise the cover of Petri dish B slightly and wipe the entire surface of the agar with the cotton ball (Figure 2). This spreads a sheet of bacteria over the agar. Remove the cotton ball, close the lid and drop the cotton ball onto the aluminum foil piece used for disposal.

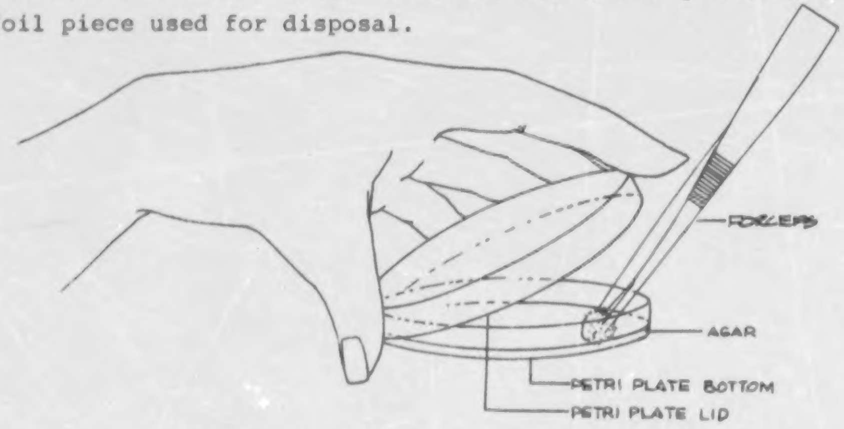


FIGURE 2: **How to swab an agar surface.**

11. Now you are ready to add an organism to Petri dish B. Locate one of the soil organisms that you selected. If it is a fungal colony, follow the directions in A below; if it is a bacterial colony, follow the directions in B on the next page.

A. To transfer a fungal colony, sterilize the forceps as in Step 8 above. Lift the lid of Petri dish A slightly and use the forceps to cut out a section of agar 2 to 3 mm across with fungus on it. (It's all right to cut into the fungal growth to do this.) Then transfer the piece of agar (with the forceps) from this plate to one side of Petri dish B, as shown in Figure 3 on the following page.

Use sterile techniques. Place the agar chunk in Petri dish B upside down so that the fungus touches the agar in the plate, and press the chunk down gently to make it stick. Remove the forceps and close the lid. Sterilize the forceps again.

B. To transfer a bacterial colony, use an inoculating loop. To sterilize the loop, hold the loop and 3 to 4 centimeters of the wire above it in a gas flame. As soon as the loop and wire begin to turn red, they are sterile. Remove the loop from the flame and let it cool in the air for a few seconds. Next, lift the lid of Petri dish A slightly and scrape the surface of the selected bacterial colony until some material is rubbed off. (Note: you do not necessarily have to see bacteria on the loop. If you have touched the colony with the loop, assume bacteria have been transferred onto the loop.) Remove the loop and close the lid. Raise the cover of Petri dish B slightly and stroke the loop onto a small area of the agar near one side of the dish, as indicated in Figure 3. Remove the loop and close the lid. Sterilize the loop again.

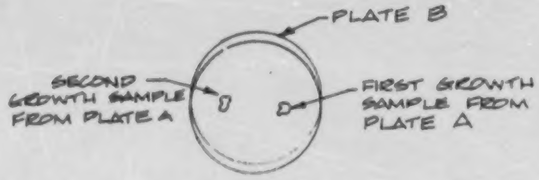


PLATE B
SECOND GROWTH SAMPLE FROM PLATE A
FIRST GROWTH SAMPLE FROM PLATE A

FIGURE 3: Locations of growth samples.

12. Repeat Step 11 with the second soil organism you selected from plate A.

13. Incubate the agar plate upside down for 24 to 48 hours at room temperature.

14. Put the piece of aluminum foil with the used cotton ball inside it into a special beaker for disposal at the stock table.

15. Now you will observe the fungal colonies on plate A closely. Observe the following characteristics and record.

    a. Color(s) of the various fungal growths.
    b. Shape and general appearance of the various growths.
    c. Any other visible characteristics.

16. With low power and lots of light, examine some fungal colonies through the bottom of the Petri dish. Keep the dish closed. The long thread-like projections are called hyphae (HI-fee), which comes from the Greek word for "webs" (Figure 4).

Most of the fungus consists of hyphae. Also, look for small, round, dark bodies. These are reproductive structures. They are similar to the seeds and fruits of other plants in that they can give rise to new fungi. Sketch some reproductive structures and their adjoining hyphae on a data sheet. Indicate the magnification used.

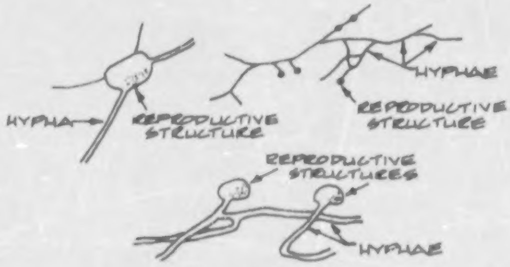


FIGURE 4: Views of various fungi, magnified 100 times.

PART III: CHECKING FOR ANTIBIOTIC ACTIVITY

INTRODUCTION:

In Part II you prepared an agar plate with bacteria and then added organisms grown from soil. Now you will observe the plate to see whether the organisms from the soil inhibited the growth of the bacteria. You may wish to review the flow chart before continuing.

MATERIALS:

agar plate B (from Part II)
ruler

PROCEDURE:

1. Obtain Petri dish B.

2. Observe the plate. Look for a clear or relatively clear area around either sample of soil organism that you added. Such a clear area is called a "zone of inhibition." It results when few or no bacteria grow around the soil organism because the soil organism produces an antibiotic that prevents the bacteria from growing.

For each soil organism record whether a zone of inhibition is present or absent. If present, record the approximate width of the zone.

DISCUSSION QUESTIONS:

PART I:

1. At what points in the procedure may organisms other than those in the original soil sample have contaminated the sample? What measures could be taken to prevent this?

2. What is agar? nutrient agar? (An encyclopedia or other reference may prove helpful.)

PART II:

1. The organisms that grew from the diluted soil sample represent only a fraction of all the living organisms that were in the sample when it was placed on the plate. Speculate on how this is possible.

2. If you wanted more colonies on Petri dish A, how could you change the procedure in Part I to produce them? How could you change the procedure to produce less colonies?

3. A soil sample is diluted 5,000 times. One ml of the soil suspension is then found to grow into 150 colonies on an agar plate. How many microorganisms per ml of soil were there in the soil sample before it was diluted, assuming one colony comes from one organism and that the agar plate was not contaminated by other organisms?

4. Bacteria and fungi on agar plates can be easily seen with the naked eye. Why then are they often referred to as "microscopic organisms?"

5. If fruit is left to sit, it usually becomes covered with fungus after a while. Why?

PART III:

1. Were there any organisms present on your plate other than the two soil organisms and the bacteria you tested them with? If so, how is this possible?

2. What advantage is it to a soil organism to be able to produce an antibiotic against other organisms?

LABORATORY ACTIVITY 18: TESTING ANTIBACTERIAL AGENTS

GENERAL INTRODUCTION:

The purpose of this activity is to compare the effects of some antibacterial compounds on bacterial growth. These substances include household disinfectants, antiseptics and laboratory chemicals.

On the first day, you will expose a sample of bacteria to an antibacterial agent for two different lengths of time. Then after the different times you will transfer samples of this mixture into nutrient broth. (See the flowchart on the following page.) Those bacteria still alive after the chemical treatment will grow well in the nutrient broth. By measuring the amount of growth on the second day, you can tell how effective your antibacterial agent was.

You will be provided with nutrient broth that is sterile (free of microorganisms). To the sterile broth, you will add the test bacteria. It is important to use sterile techniques to ensure that no other microorganisms contaminate the nutrient broth, since contamination would invalidate the conclusions. Sterile technique involves taking special care to prevent microorganisms from the outside, such as on dust particles, from getting into your broth. In Part I, you have the opportunity to practice two procedures that call for sterile technique. In Part II you will use sterile techniques in a test of antibacterial agents and in Part III you will observe the results.

PART I: STERILE TRANSFER TECHNIQUES

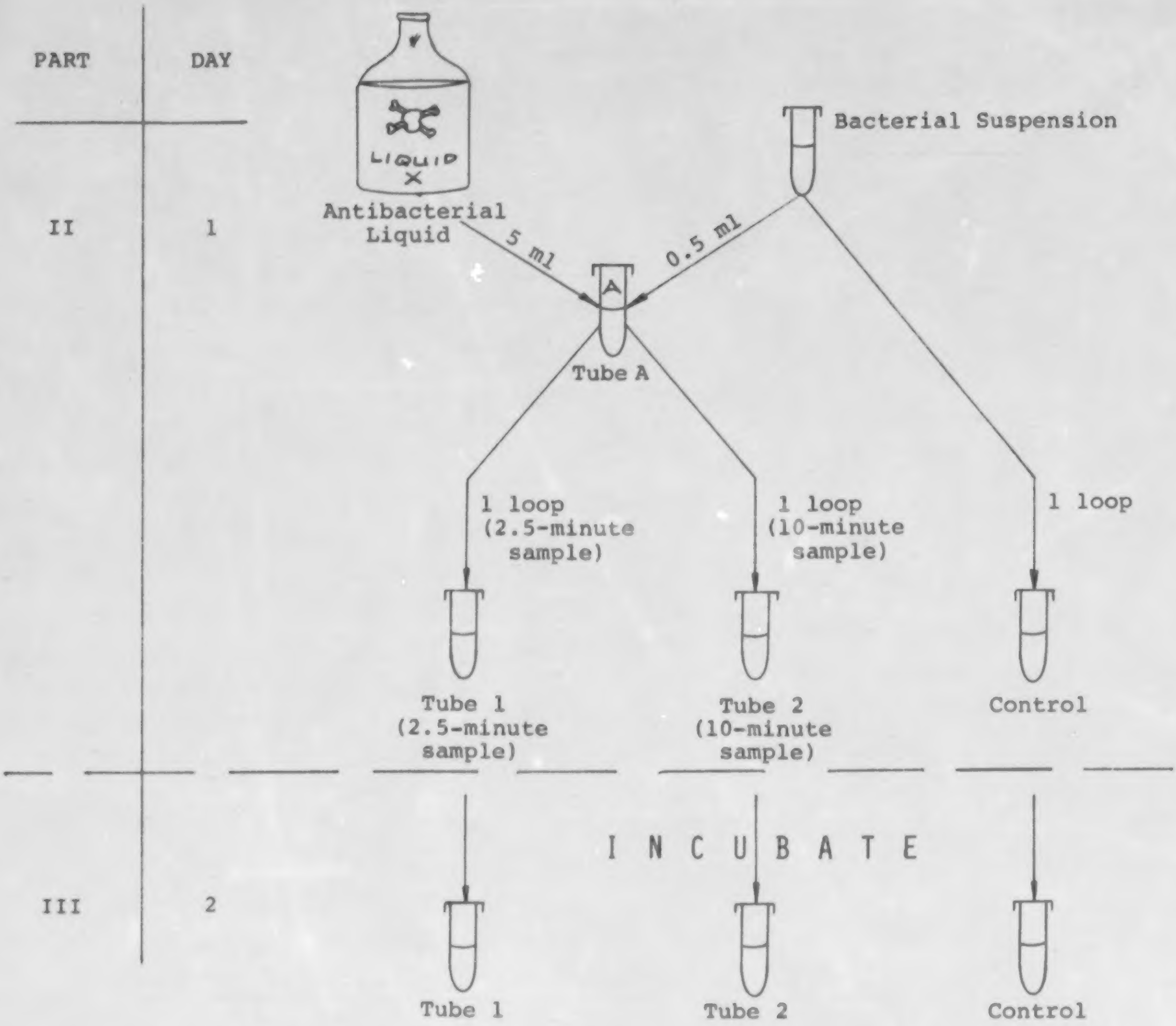
INTRODUCTION:

In this part, you will practice two procedures requiring sterile technique. Both involve transfers--one with a pipet and the other with a loop. By practicing these techniques, you will be able to perform them more easily in Part II and in later activities when sterile techniques are crucial to the success of the activity.

MATERIALS:

2 test tubes, 16 x 125 mm
2 test-tube caps, 18 mm
1-ml pipet wrapped in aluminum foil
250-ml beaker
inoculating loop
gas burner
test-tube rack
clock with second hand

FLOWCHART


PART
DAY
II
1
III
2
LIQUID X
Antibacterial Liquid
Bacterial Suspension
5 ml
0.5 ml
A
Tube A
1 loop (2.5-minute sample)
1 loop (10-minute sample)
1 loop
Tube 1 (2.5-minute sample)
Tube 2 (10-minute sample)
Control
INCUBATE
Tube 1
Tube 2
Control

PROCEDURE:

1. Label one test tube "1" and the other "2." Fill them about a third full of tap water, and cap them. Assume, in Part I, that tube 1 contains a suspension of bacteria and tube 2 an antibacterial liquid. In the next step, you will transfer 0.5 ml of "bacterial suspension" into the tube containing "antibacterial liquid." The correct technique for doing this is probably more complicated than you would expect. Read and try to visualize all of Step 2 before actually performing the operations.

2. To make the transfer, proceed as follows.

a. Obtain a 1-ml pipet wrapped in aluminum foil. Unwrap the aluminum foil and hold the pipet near the top (the end away from the delivery end). In sterile technique, the lower end of a pipet is never touched by the hands or fingers.

b. Remove the cap from tube 1 (the tube containing simulated bacterial suspension) by grasping the cap between two fingers as shown in Figure 1. (The exposed end of the cap should not be allowed to touch any surface other than the fluid inside tube 1. The particular grip shown in the figure helps to keep the cap away from non-sterile surfaces and also leaves the fingers needed for pipetting free.)

c. Flame the rim of the test tube. This is done to kill any microbes that have landed inside the test tube near the rim. In this operation, simply pass the upper 1 to 2 cm of the tube quickly (about 1 second) through the flame of a gas burner.

d. Place the pipet into tube 1 and fill it with 0.5 ± 0.05 ml of "bacterial suspension." Pipet carefully to avoid drawing bacteria into your mouth. (If the fluid really included bacteria, a mistake could be harmful.) Note: the pipet should not touch any non-sterile surface other than the fluid in tube 1.

e. Remove the pipet with the liquid in it. Flame the rim of the tube as in Step 2c. Replace the test-tube cap. During this operation, be careful not to spill any fluid from the pipet.

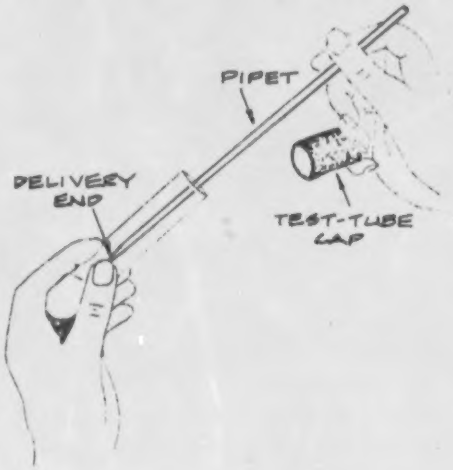


FIGURE 1: Transferring bacteria with a pipet.

f. Remove the cap from test tube 2 (the tube with simulated antibacterial fluid) as you did in Step 2b. Flame the rim of the tube, empty the contents of the pipet into the tube (you may have to blow out the last few drops of fluid in the pipet), flame the rim of the test tube once again and replace the cap. Place the used pipet in the 250-ml beaker.

3. Practice Step 2 until you can do it quickly and smoothly. Speed is important because during the transfer, there is a chance of contaminating the contents of tube 2. The faster the transfer, the less the chance of contamination.

4. To evaluate your skill in the transfer technique, have another student score you on speed and accuracy in Step 2. Begin with 100 points and subtract points for errors or add points as directed. Note that the severity of the penalty indicates how serious an error is.

SPEED OF OPERATION

Time for entire operation, seconds*	Bonus or Penalty
< 30	+10
30 - 60	0
61 - 120	-10
>120	-25

*If a step is missed, ignore this table and subtract 75 points. If more than one step is missed, subtract 100 points.

ACCURACY OF OPERATION

Error	Penalty
Dropped a test tube or pipet	-75
Pipetted bacteria into mouth	-50
Dropped a cap or set cap on desk	-25
Touched lower half of pipet with finger or hand	-25
Lost more than 1 drop from pipet	-25
Forgot to blow drop out of pipet	-20
Pipet touched article of clothing (such as a sleeve) or desk top or outside of tube during transfer	-15
Lost 1 drop from pipet	-15
Held the cap between the wrong two fingers	- 5
Forgot to put pipet into 250-ml beaker	- 5
Other minor error spotted	- 5

If you scored 95 or more, you're a born microbiologist. If you scored 80 to 94, you're probably ready to proceed. If you scored less than 80, try again. (If you scored less than 25, proceed to the autoclave for decontamination.)

5. The second procedure is a sterile loop transfer. In it, an inoculating loop is used to transfer bacteria from one tube to the next. Use two test tubes. Label one "A" and the other "1."

6. To make the sterile loop transfer, proceed as follows.

a. Sterilize the loop by holding the loop end as well as 3 or 4 cm of the wire above it in a gas flame. As soon as the loop and wire begin to turn red, they are sterile. Remove the loop from the flame and let it cool in the air for a few seconds.

b. Remove the test-tube cap from tube A by grasping the cap as in Figure 2.

c. Flame the rim of the test tube.

d. Put the loop into the liquid, withdraw the loop, flame the tube again, and replace the cap.

e. Remove the cap from the other tube (tube 1) in the same manner as above. Swish the loop around in the liquid for a few seconds. Withdraw the loop, flame the tube and replace the cap.

f. Flame the loop again to sterilize it.

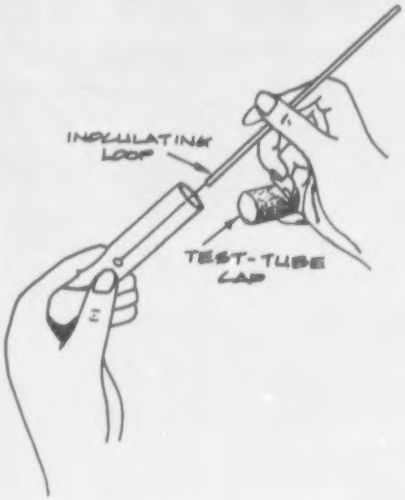


FIGURE 2: How to do a loop transfer.

7. Practice Step 6 until you can do it smoothly and quickly. You may wish to devise a scoring system similar to the one in Step 4 for evaluating your technique. If so, keep in mind that the loop transfer should only take about half as much time as the pipet transfer.

PART II: EXPOSING BACTERIA TO AN ANTIBACTERIAL AGENT

INTRODUCTION:

In this part, as shown in the flowchart, you will mix bacteria with an antibacterial agent for different lengths of time and then transfer samples to nutrient broth. Review the flowchart before proceeding.

MATERIALS:

antibacterial agents
test tube, 16 x 125 mm
test-tube cap
empty capped test tube, sterile, 16 x 125 mm
3 capped test tubes containing nutrient broth, sterile, 16 x 125 mm
10-ml pipet, sterile (wrapped)
1-ml pipet, sterile (wrapped)
glass-marking pencil
test-tube rack
inoculating loop
gas burner
germicide

PROCEDURE:

1. Disinfect (clean) a large area of the table top as in Laboratory Activity 17. You may wish to review the Warning at the end of the General Introduction to Laboratory Activity 17.

2. In the uncapped test tube, obtain about 6 ml of an antibacterial liquid; either an antibacterial agent provided or one you have brought. Then cap the tube. In this activity, assume that this fluid is sterile and that sterile techniques are not needed yet. (If you have brought a liquid that is normally diluted before use, such as a household disinfectant, then first make the dilution that the label calls for.) Record the name and description of the antibacterial agent, its concentration (if given) and any dilutions made.

3. Unwrap the sterile pipet packet slightly so that the ends you put your mouth to are exposed (not the delivery ends). Remove the 10-ml pipet and close the packet. Using the 10-ml pipet, pipet 5 ± .5 ml of the liquid into the empty sterile capped test tube. (Use sterile techniques.) Label this tube "A."

4. Now you will add bacteria to tube A and incubate the tube. It will be necessary to have the following items conveniently arranged at your work table.

3 capped test tubes containing sterile nutrient broth
test tube of bacterial culture
test-tube rack
sterile 1-ml pipet in its wrapper
gas burner
inoculating loop

5. Label three capped test tubes of broth "1," "2" and "C." To transfer bacteria into tube C (the antibacterial solution), unwrap the sterile 1-ml pipet slightly so that the end with the cotton plug is exposed (not the delivery end). (The cotton plug is an extra safety factor to prevent bacteria from being pipetted into the mouth.)

6. Transfer 0.5 ± .05 ml from the test tube containing the bacterial culture to tube A. Use sterile techniques.

As soon as the transfer is complete, record the time to the nearest 5 seconds. This will be referred to as "time zero." In 2.5 minutes, you will perform Step 7. In the meantime, discard the pipet by placing it in the 600-ml beaker. Shake the tube thoroughly to distribute the bacteria uniformly. (Take care not to spill any fluid.)

7. In 2.5 minutes after time zero, transfer a loop of fluid from tube A into tube 1 (Figure 3). Use sterile technique.

8. Ten minutes after time zero, transfer a loop from tube A to tube 2.

9. Now you will need a control tube. The control will contain a bacterial suspension that has not been mixed with an antibacterial liquid.

To make the control, transfer a loop from the culture tube to tube C using sterile technique.

10. Initial tubes 1, 2 and C and incubate them for 24 hours at 35 ± 3 °C. Put tube A and the culture tube in designated places.

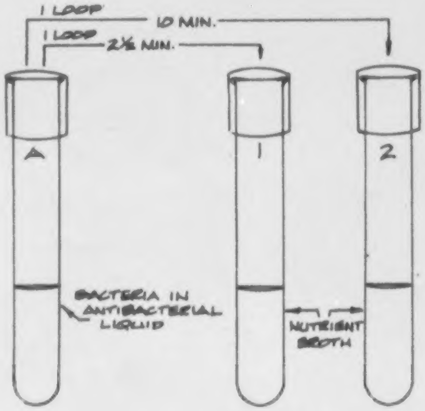


FIGURE 3: Transferring bacteria at different times.

PART III: OBSERVING BACTERIAL GROWTH

INTRODUCTION:

In the first part of this activity bacteria were treated with chemicals for 2.5 and 10 minutes and then transferred to nutrient broth. Now you can determine the effect of the chemicals on the bacterial growth. The more bacteria, the greater the turbidity (cloudiness). Therefore, by using the BIP colorimeter to measure turbidity you can compare growth in different tubes.

MATERIALS:

BIP colorimeter
tubes 1, 2 and C from Part II
sterile nutrient broth tube
screwdriver

PROCEDURE:

1. Program the BIP for colorimetry and allow it to warm up for at least 10 minutes before use.

2. Obtain the tubes prepared in Part II.

3. Standardize the colorimeter at 100% transmittance using a sterile nutrient broth tube as the blank.

4. Agitate tube C to distribute its contents thoroughly, but be careful to avoid spills. Determine and record its percentage transmittance.

5. Agitate the other tubes and determine and record their percentage transmittances.

6. Determine the corresponding absorbances.

7. From the absorbance values, you can estimate the actual number of bacteria per ml of broth. The greater the absorbance, the higher the concentration of bacteria.

Use the standard graph to estimate the number of bacteria per ml for each tube. Record your results. Don't be surprised if the numbers are very high--bacterial populations can grow to concentrations of 10^7 bacteria per ml or even higher.

DISCUSSION QUESTIONS:

1. Did you find a difference in the bacterial population at the two different times? If so, why?

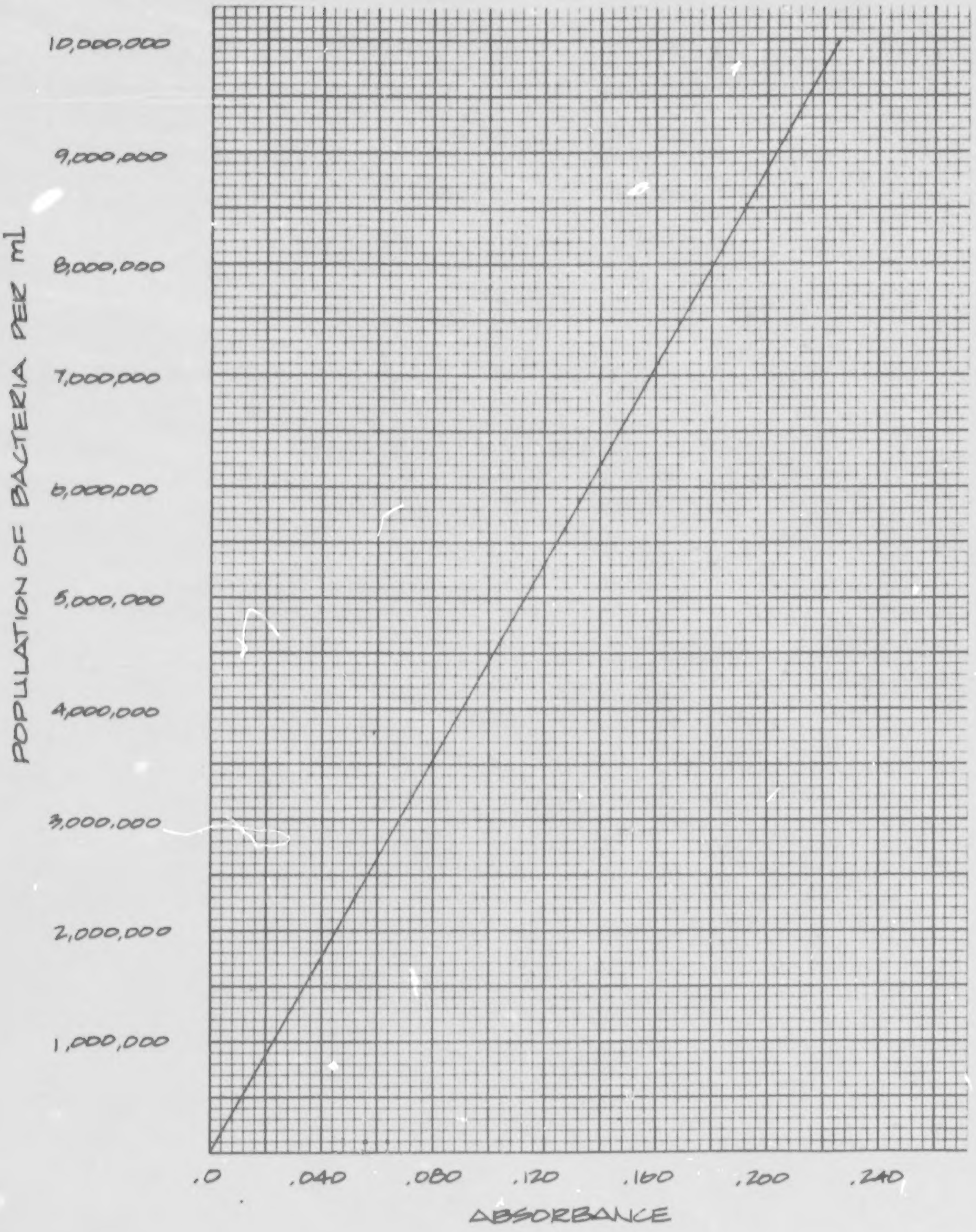
2. Was there a difference in population between the control tube and the other tubes? Explain.

3. Were there differences in population among the various agents tested by the class? Explain.

4. Why does the absorbance of a solution increase with the number of bacteria?

5. A disinfectant tested in the activity may only have had a minor effect on population, but it could still be an excellent disinfectant for household surfaces. How is this possible? How could you run a test to find out how well a disinfectant kills bacteria in a practical application?

6. If someone spilled a culture of bacteria on the lab table, how would you disinfect the area?


10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
POPULATION OF BACTERIA PER ml
.0
.040
.080
.120
.160
.200
.240
ABSORBANCE

LABORATORY ACTIVITY 19: TESTING THE ANTIBIOTIC ACTIVITY OF *PENICILLIUM*

GENERAL INTRODUCTION:

The purpose of this activity is to test a mold (fungus) for antibacterial activity. The mold you will use is a species of *Penicillium*, the type of mold that produces penicillin.

In the first period you will spread some bacteria on the surface of nutrient agar and then place a chunk of *Penicillium* mold on the agar. On the second day you will observe the agar to see whether the bacteria have been inhibited from growing near the *Penicillium*.

To ensure that no other organisms contaminate the nutrient agar, it will be important to use sterile technique. Sterile technique will help to prevent microorganisms from the outside, such as on dust particles, from getting on the agar.

PART I: INOCULATION OF NUTRIENT AGAR

INTRODUCTION:

In this part the contents of a sterile tube of nutrient agar will be melted and then poured into a Petri dish. Then, you will spread bacteria over the surface of the nutrient agar and add *Penicillium* mold.

MATERIALS:

- capped test tube containing sterile nutrient agar
- sterile Petri dish
- hot water bath
- germicide
- paper towels
- glass-marking pencil
- 250-ml beaker
- forceps
- tube with bacterial suspension
- packet of sterile cotton balls, wrapped in aluminum foil
- alcohol in a cup or beaker
- aluminum foil for disposal of used cotton balls

PROCEDURE:

1. Review the *Warning* in the General Introduction to Laboratory Activity 16.

2. Clean the work area as in Laboratory Activity 16, Part 1, Step 1.

3. Obtain a test tube of sterile nutrient agar and melt the agar in a boiling water bath. (This should take about five minutes.) Do not remove the cap from the test tube, since this would let dust in.

4. When the agar is melted, let it cool. Directions for this procedure are given in Laboratory Activity 16, Part 1, Step 4, for *two* tubes. Follow those directions, but apply them to your *one* tube instead.

Meanwhile, obtain a sterile Petri dish and place it on the table with the lid on top. Do not open it.

5. As soon as the agar tube has reached the proper temperature, pour the agar into the Petri dish using sterile technique. You may wish to review the illustration

in Laboratory Activity 16, Figure 1. Proceed as follows: remove the cap from the tube, raise the Petri-dish lid slightly and pour the contents of the tube into the sterile Petri dish. (To keep dust out, do not remove the Petri-dish lid completely when pouring agar into the dish.) Replace the Petri-dish lid immediately.

6. Allow about 10 minutes for the agar in the Petri dish to harden and cool. Do not move the Petri dish while it is cooling; moving it can make the agar uneven or lumpy.

7. Now you will add bacteria and Penicillium to the agar plate. To do this, it will be necessary to have the following items conveniently located at your work table:

packet of sterile cotton balls, wrapped in aluminum foil
piece of aluminum foil to put used cotton balls into
forceps
beaker or cup with alcohol
gas burner

8. To coat the surface with bacteria, a sterile cotton ball will be used. The directions for this procedure are given in Laboratory Activity 16, Part II, Steps 7, 8,9, and 10. (Step 10 mentions a Petri dish "B"--treat your Petri dish like Petri dish "B.")

9. Next, Penicillium will be added to the Petri dish. Obtain a Petri dish containing Penicillium mold. Sterilize the forceps as in Laboratory Activity 16, Part II, Step 8. Lift the lid of the agar plate slightly and use the forceps to cut out a 2 to 3 mm section of agar containing Penicillium mold. (It's all right to cut into the mold to do this.) Then use the forceps to transfer the piece of agar from the plate onto the middle of the agar in your freshly prepared plate. Turn the agar chunk upside down so that the mold touches the agar in the plate, and press the chunk down gently to make it stick. Remove the forceps, close the lid and sterilize the forceps again.

10. Incubate your Petri dish upside down in the incubator at a temperature of 35 ± 3 °C for a day or more.

11. Dispose of the bacteria-soaked cotton ball as directed.

PART II: OBSERVATION OF PENICILLIUM AND BACTERIAL GROWTH

INTRODUCTION:

In Part I, you added Penicillium mold to bacteria on a nutrient agar plate. In this part you will observe the bacterial growth to see whether it has been inhibited by the Penicillium mold.

MATERIALS:

Petri dish from Part I
mm ruler

PROCEDURE:

1. Obtain the Petri dish from Part I.

85

2. Observe the plate. It may be helpful to hold it up to the light. Look for a clear or nearly clear area around the Penicillium. Such a clear area is called a zone of inhibition. It occurs when few or no microbes grow around an antibacterial agent such as penicillin.

If a zone of inhibition is present, record the width of the clear area to the nearest mm.

DISCUSSION QUESTIONS:

1. At which points in the activity may contaminating microorganisms have gotten into the agar?

2. Why isn't penicillin effective against allergies?

3. If there was no zone of inhibition, speculate as to why. (Several reasons are possible.)

4. A Penicillium mold may be effective against bacterial growth in an agar plate. Yet, if penicillin were extracted from the mold and tested in animals that have a bacterial disease, it might prove useless against the disease. Speculate as to why.

LABORATORY ACTIVITY 20: TESTING THE EFFECTIVENESS OF ANTIBACTERIAL AGENTS

INTRODUCTION:

The purpose of this activity is to test the effectiveness of various antibacterial agents. The paper-disc method is used in the test. The procedure is similar to the one used in hospital laboratories to determine the most effective antibiotic for a particular bacterium.

In the activity, bacteria are placed on nutrient agar in the presence of paper discs that contain antibacterial agents. After a day of incubation bacterial growth should be evident. Bacteria should grow well everywhere on the plate except near the antibacterial discs. Around the discs you may find clear (or nearly clear) zones where bacterial growth has been inhibited. The size of the zone indicates how well the antibacterial agent prevents bacterial growth; the larger the zone, the more effective the antibacterial agent.

FLOWCHART

Melt nutrient agar
↓
Pour plates
↓
Swab bacteria on plates
↓
Add antibacterial agents
↓
Incubate plates
↓
Observe plates

MATERIALS:

broth culture of Serratia marcescens
broth culture of Staphylococcus aureus
2 capped test tubes containing sterile nutrient agar

2 sterile Petri dishes
4 sterile filter-paper discs
2 antibacterial liquids
2 streptomycin antibiotic discs
2 penicillin antibiotic discs

forceps
hot water bath
glass-marking pencil
incubator
test-tube holder
germicide
gas burner
alcohol
beaker, 50-ml
packet of sterile cotton balls, wrapped
  in aluminum foil
aluminum foil

PROCEDURE:

1. With a glass-marking pencil, divide the bottom of each Petri dish into four sections (Figure 1). Do not remove the covers of the dishes. Number the sections 1, 2, 3 and 4. Mark one of the dishes "SM" (for S. marcescens) and the other dish "SA" (for S. aureus). Label the cover of the dish with your initials.

2. Obtain two test tubes of sterile nutrient agar and melt the agar in a boiling water bath. (This takes about five minutes.) Do not remove the caps from the tubes; this could let in dust, which would contaminate the agar.

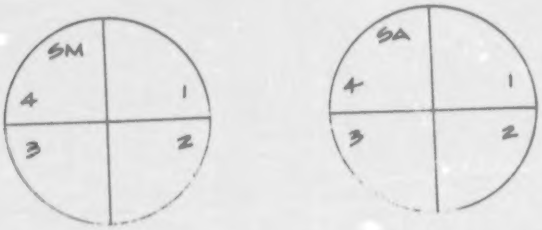


FIGURE 1: Labeling the Petri-dish bottoms.

3. When the agar has melted completely, use a test-tube holder to remove the test tubes from the hot water bath. Let the tubes cool until they are still hot, but not hot enough to burn you. The agar will still be liquid. Meanwhile, arrange the two sterile Petri dishes so that the lids are on top. Do not open the Petri dishes.

4. When the agar has cooled, raise one of the Petri-dish lids slightly (see Figure 2) and pour the contents of one of the tubes into the sterile Petri dish. (To keep dust out, do not remove the Petri-dish lid completely when pouring agar into the dish.) Replace the lid immediately. Repeat the pouring procedure with the second Petri dish and agar tube.

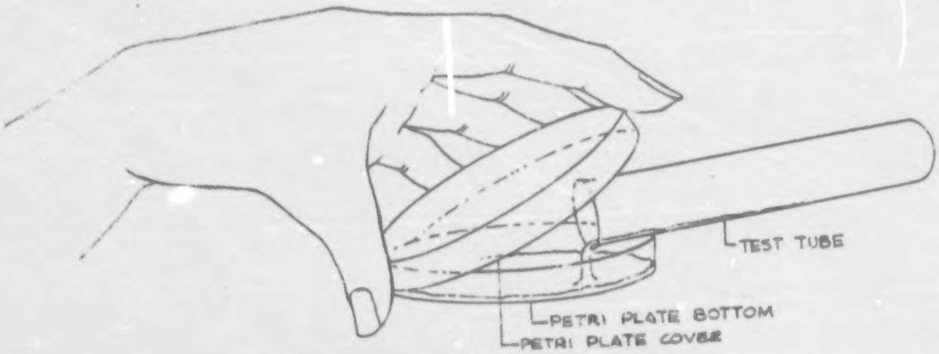


FIGURE 2: How to pour agar.

5. Allow about 15 minutes for the agar in the Petri dishes to harden and cool. Remember not to move the Petri dishes while the agar is cooling.

6. To swab the agar plates with a bacterial culture, it is necessary to have the following items readily available at your work table.

broth culture of bacteria
aluminum foil to put used cotton balls into
packet of sterile cotton balls, wrapped in aluminum foil
forceps
beaker containing alcohol
gas burner
agar plate

7. When the agar has hardened, carefully open the packet of sterile cotton balls--do not touch the cotton with your fingers. Expose the cotton balls just enough to be able to pick them up with the forceps.

8. Sterilize the tips of the forceps by dipping them into alcohol and then touching them briefly to a gas flame. Allow the alcohol to burn off. Caution! Fire hazard! Don't let the alcohol drip.

9. Pick up one cotton ball with the forceps. Holding the cotton with the forceps, remove the cap from the test tube containing bacteria (as shown in Figure 3). Dip the cotton into the broth, letting the broth soak in. (If necessary, tilt the tube.) Don't let go of the cotton. Withdraw the cotton, allow extra broth to drip into the tube, and replace the cap.

10. Raise the cover of the Petri dish slightly and gently wipe the entire surface of the agar with the cotton ball. This spreads a sheet of bacteria over the agar. Then drop the cotton ball onto the aluminum foil used for disposal.

11. Sterilize the forceps as in Step 8. Pick up a penicillin disc with the forceps and place the disc in the section of the dish marked "1." Then place a streptomycin disc in the section marked "2." (Note: the discs should be placed 2 to 3 cm apart.)

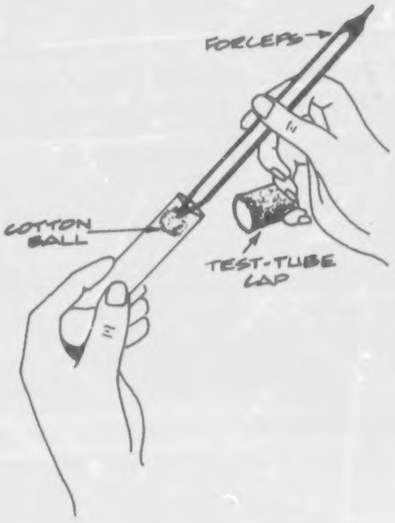


FIGURE 3: Soaking a sterile cotton ball with broth solution.

12. Obtain a packet of sterile filter-paper discs. (Note: the discs should be handled with the same aseptic technique as the cotton balls.) With forceps, pick up a sterile filter-paper disc by the outer edge. (If the discs stick together, use the forceps to separate them--not your fingers.) Wet the disc by touching the edge to the surface of one of the liquid antibacterial agents. Allow the disc to take up the agent until it is completely wet but not dripping. Place the disc on the section marked "3." Record the name of the antibacterial agent in your data sheet.

13. Wet a second filter-paper disc with a different antibacterial liquid. Place the disc on the section marked "4," and then record the name of the antibacterial agent.

14. Repeat Steps 6 through 13 with the second Petri dish and the second bacterial culture.

15. Incubate the Petri dishes at 35 ± 3 °C for one to two days. The dishes should be incubated upside down. This prevents condensation from confusing the results.

16. Dispose of the used cotton balls as directed by your instructor.

17. After at least a day of incubation, observe the bacteria growing on the agar. Check the areas around the antibacterial discs for clear zones where bacterial growth has been inhibited. Note which clear zones are the largest--the agents in these zones are the most effective in preventing the growth of the bacterium used. Record the radii of the clear zones in mm. For each type of bacterium, rate the effectiveness of the four antibacterial agents.

DISCUSSION QUESTIONS:

1. Which antibacterial agent is most effective in preventing the growth of S. marcescens? of S. aureus?

2. Which antibacterial agent is least effective in preventing the growth of S. marcescens? of S. aureus?

3. When a clear zone is present, why does the number of bacteria increase at greater distances from the discs?

4. Discuss the effects of different antibacterial agents with your classmates. Use the class data to rank all of the antibacterial agents according to the ability of the agents to inhibit the growth of S. marcescens and S. aureus under the conditions in your laboratory.

5. Why do the clear zones around the discs have different diameters?

6. An antibiotic that inhibits the growth of a bacterium in a Petri dish may be ineffective when used in the body to combat disease. Speculate as to why.

LABORATORY ACTIVITY 21: MAKING WAVES AND PURE-TONE AUDIOMETRY

GENERAL INTRODUCTION:

In Part I of this activity you will make waves with a coiled spring known as a slinky. Part II involves pure-tone audiometry, and it will probably be a few days before the entire class can finish it because it requires both scarce equipment and a quiet environment.

PART I: MAKING WAVES

INTRODUCTION:

In this part you will use a slinky to produce both longitudinal and transverse standing waves with various frequencies, wavelengths, periods and amplitudes. From measurements you will make, you will determine the speed of movement of waves in the slinky. From similar measurements on standing sound waves you will later determine the speed of sound in air.

MATERIALS AND SPACE REQUIREMENTS:

slinky
masking tape
clock or watch with a second hand
smooth floor surface
open rectangular floor space, approximately 3 meters by 1.5 meters

PART IA: TRAVELING WAVES

PROCEDURE:

Each student should try producing both longitudinal and transverse waves.

1. Tape one end of the slinky to the wall. Stretch the slinky to a length of about 3 meters (Figure 1).

2. Bounce a single half transverse wave off the wall by giving the slinky a single quick jerk parallel to the wall (Figure 2).

3. Draw a sketch of the reflected wave on a separate piece of paper. Observe the slinky closely. If the wave leaves your hand looking like a peak, does it return looking like a peak or a valley? (1)

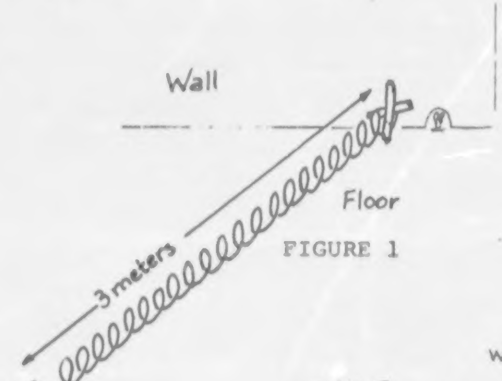


FIGURE 1

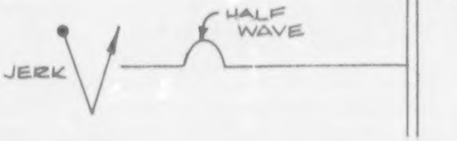


FIGURE 2

4. Generate another single traveling transverse wave and observe that it bounces back and forth a few times before it dies out. The greater the amplitude of the initial impulse, the longer it will last. Generate a single traveling wave and record the number of times it bounces back and forth before it dies out. (2)

5. Produce a single longitudinal wave by giving the slinky a quick jerk perpendicular to the wall (Figure 3 following page).

6. How many times can you make the wave go back and forth? Record the maximum number of times you were able to make it "yo-yo." (3)

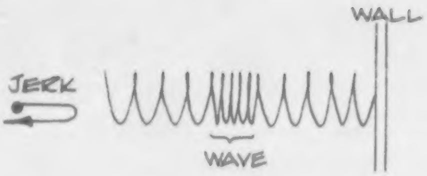


FIGURE 3

PART IB: STANDING WAVES

INTRODUCTION:

Standing waves result from the addition of waves traveling in opposite directions. With this set-up waves approaching and reflected from the wall will add. In this part you will practice making standing transverse and longitudinal waves. The set of graphs on the following page represents a sequence of snapshots of a standing full wave. A standing transverse wave takes the shape of a sine wave. The amplitude of the waves varies regularly with time.

Observe that the displacement (vertical coordinate) is always zero at points a, c and e (Figure 4). These points are called nodes; no motion occurs at nodes. Maximum motion occurs at b and d. These points are the locations of antinodes. The displacement at the antinodes varies from +2 to -2 times the amplitude of the original waves.

Some experimentation will be necessary before you successfully generate standing waves. Here are some hints.

- --Standing waves will occur only at certain frequencies of hand motion and not others.
- --To maintain a particular standing wave pattern you will need to keep to a regular rhythm or beat of hand movement.
- --Slower frequencies will produce longer waves; faster frequencies, shorter waves.

PROCEDURE:

1. Generate a transverse standing half wave in the entire length of the slinky.

2. To generate a full standing wave you must oscillate your hand at twice the frequency required to achieve a standing half wave. Generate a full standing wave in the slinky.

3. Increase the frequency of your hand motions and observe 1½ standing waves, 2 standing waves and so forth until you reach your maximum.

4. Setting up a standing longitudinal wave resembles bouncing a ball against the wall. For a half wave, the reflected compression wave will hit your hand at the peak of your backswing. Generate a standing longitudinal half wave.

5. To generate a standing longitudinal full wave you will need to double the frequency required for Step 4. Generate a standing longitudinal full wave (Figure 6).

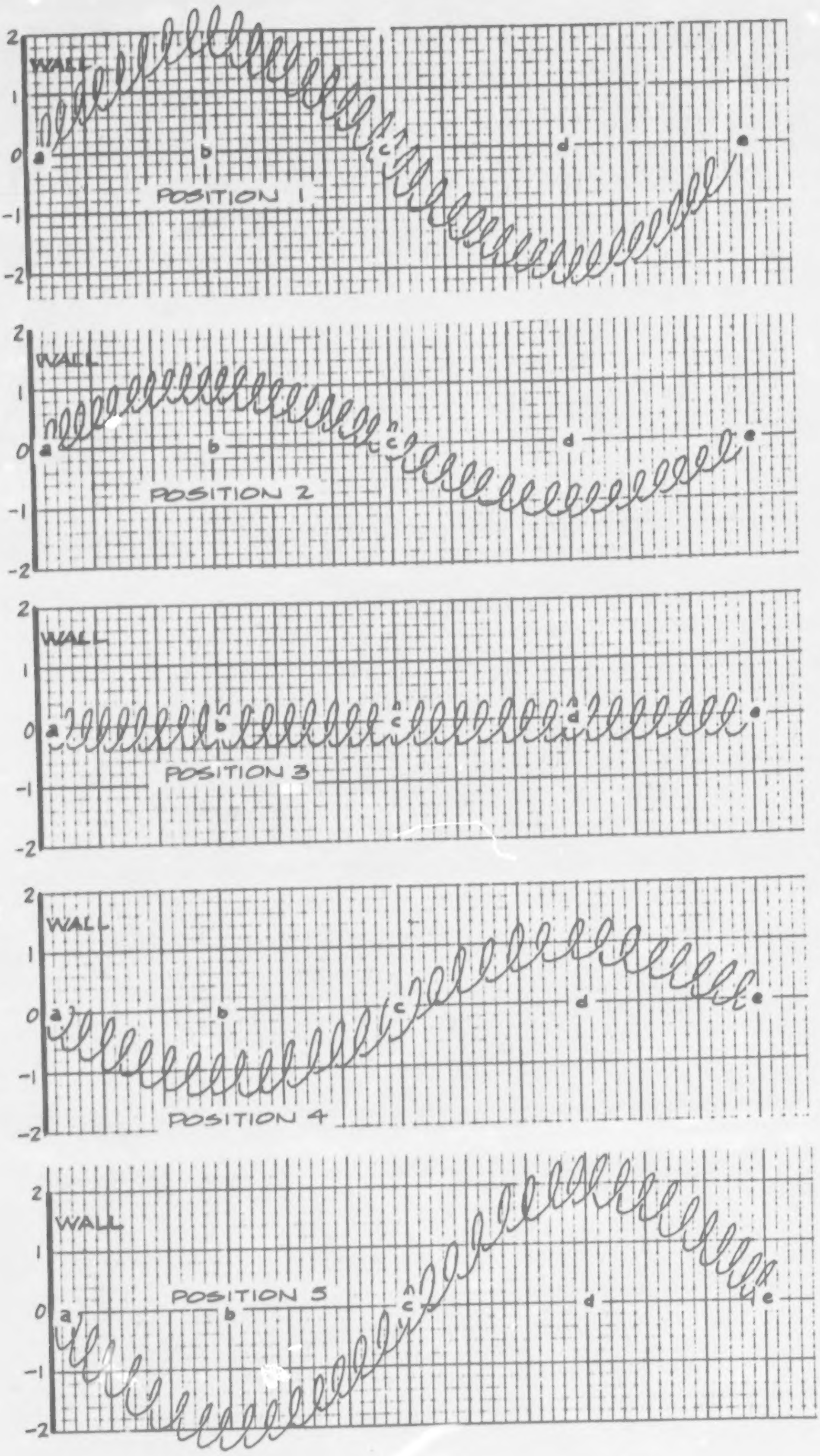

2
1
0
-1
-2
WALL
a
b
c
d
e
POSITION 1
POSITION 2
POSITION 3
POSITION 4
POSITION 5

FIGURE 4

Standing transverse waves will resemble the diagrams in Figure 5.

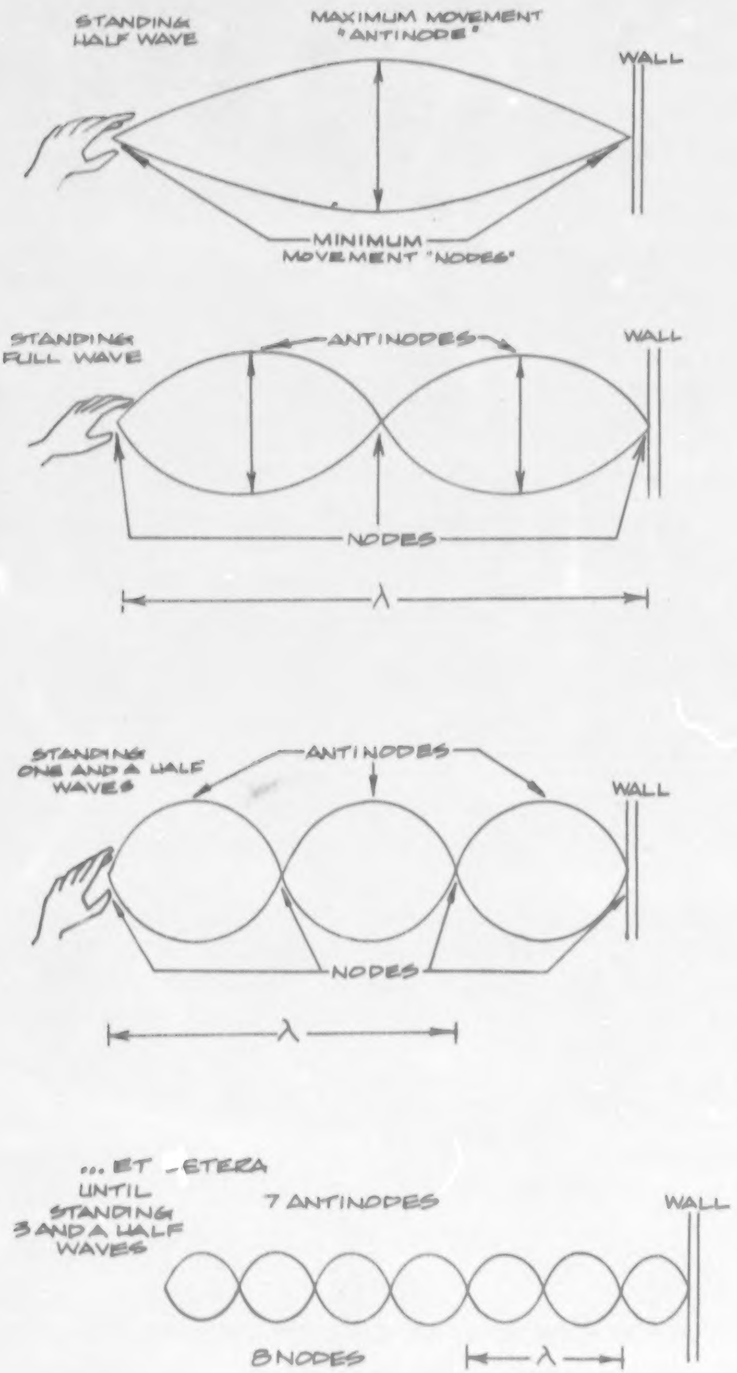

STANDING HALF WAVE
MAXIMUM MOVEMENT "ANTINODE"
WALL
MINIMUM MOVEMENT "NODES"
STANDING FULL WAVE
ANTINODES
WALL
NODES
λ
STANDING ONE AND A HALF WAVES
ANTINODES
WALL
NODES
λ
... ET CETERA UNTIL STANDING 3 AND A HALF WAVES
7 ANTINODES
WALL
8 NODES
λ

FIGURE 5

6. You can find the wave speed in the slinky by multiplying the frequency (f) by the wavelength (λ). Wave speed may then be calculated from the formula $s = \lambda f$. Stretch the slinky out to a "convenient" measured length. 3, 2.5 or 2 meters is convenient; 2.37 meters is not.

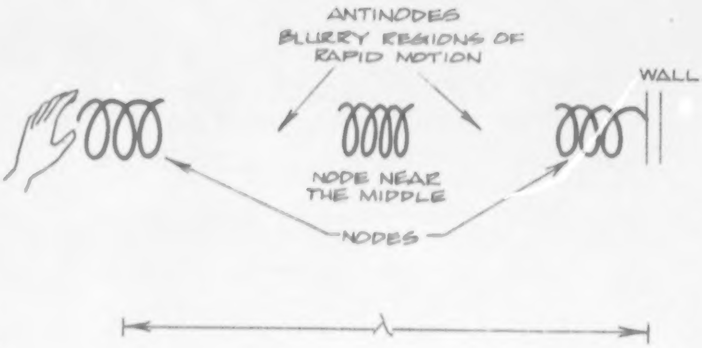

ANTINODES
BLURRY REGIONS OF RAPID MOTION
WALL
NODE NEAR THE MIDDLE
NODES
λ

FIGURE 6

7. To accomplish this step will require division of labor between three students. One acts as an "oscillator," one as a "timer" and the third as a "recorder. The different roles are described below and in Figure 7.

a. The oscillator should concentrate on maintaining a full standing wave (2 antinodes). When the timer says "start," you are to begin counting the number of hand movements. (Each count should be made with the hand in the same place as it was during the preceding count, for example, the rightmost extreme of your swing.)

b. The timer should start and stop the time interval. Use a convenient length of time: 10 or 20 seconds is convenient; 13 seconds is not. In general, the longer the time interval is, the more accurate your frequency measurement will be. In addition the timer should try to begin the time interval when the oscillator is at one of the extremes of his or her swing.

c. The recorder should record on a separate piece of paper four pieces of data for each trial: (1) the number of hand strokes; (2) the length of the time interval; (3) the stretched length of the slinky and (4) the number of wavelengths.

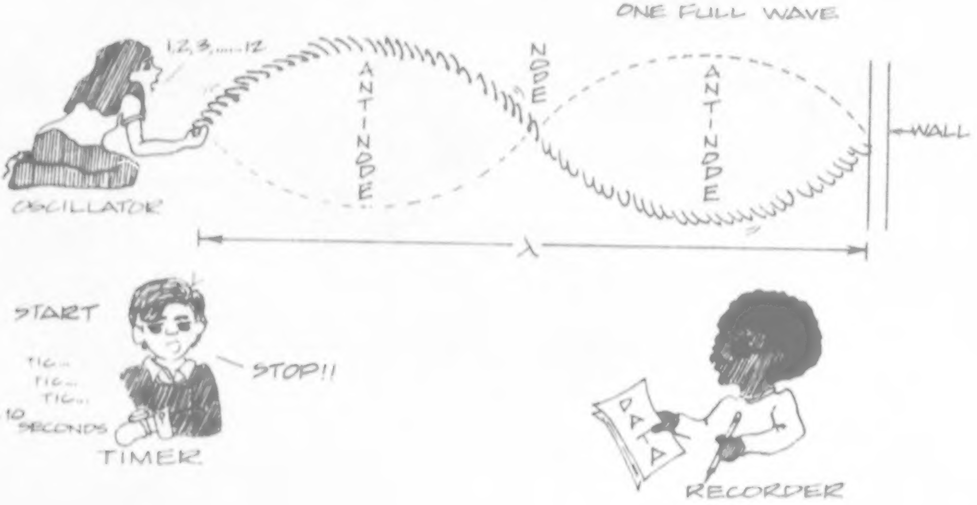

ONE FULL WAVE
1,2,3,.....12
ANTI-NODE
NODE
ANTI-NODE
WALL
OSCILLATOR
λ
START
TIC...
TIC...
TIC...
...10 SECONDS
STOP!!
TIMER
DATA
RECORDER

FIGURE 7

8. Repeat Step 7 for a standing transverse wave that has 2 waves (4 antinodes) in the length of the slinky.

9. Repeat Steps 7 and 8 for a different stretched length of the slinky.

10. Calculate the wave speed (λf) for each trial. Record your answers in terms of meters per second. This product is the speed of wave propagation in your slinky. What factors might explain any differences in the speeds calculated for the different trials? (4)

PART II: PURE-TONE AUDIOMETRY

INTRODUCTION:

As described briefly in Section 21, pure-tone audiometry is a technique used to measure a person's hearing loss. Since there probably won't be enough audiometers or stereo headphones to allow the entire class to participate in this activity at one time, this part of the activity will be spread over the next few days. Pairs of you will go to some quiet room and use either an audiometer or the BIP to test each other's hearing.

MATERIALS:

Either	or
audiometer	2 BIP's pair of medium- to hi-fi stereo headphones 24-gauge wire and wire cutters-strippers tape

PROCEDURE:

1. Calibration: If you have a real audiometer go to Step 2. If using BIP's and the calibration has been done previously, go on to Step 3.

a. Take the BIP's to a very quiet testing location if possible.

b. Program the BIP's as shown in Figure 1. Neither BIP should be plugged in at this time.

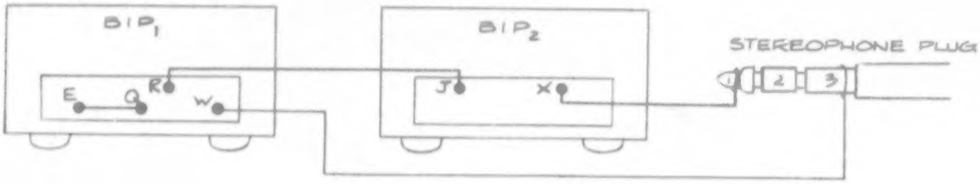


FIGURE 1

c. Plug in BIP_1, but not BIP_2. Doublecheck to make sure that you are plugging in the correct BIP by checking its programming. BIP_1 will have a programming wire between E and Q. (If both are plugged in, the BIP's may be damaged. If the wrong BIP is plugged in, the set-up will not function properly.)

d. Set the "db" dials (located on the upper-left portion of the front panel) of both BIP's to 0. Set the "freq" dial (upper-right dial) of BIP_1 to 200 and the slide switch next to it in the "down" position. This will produce a 2000-cps tone in one of the headphones.

e. Place the headphones on someone who is thought to have good hearing and adjust the "db" dial of BIP_2 (no wire between E and Q) until the subject can just barely hear the tone.

f. Repeat Step e for 5 or 6 ears to find a roughly average position of the BIP_2 "db" dial for all ears.

g. Tape BIP_2's "db" dial in the position of Step f. It should not be moved in any following step.

h. Go to Step 3.

2. The audiometric-testing apparatus will have both a frequency and a volume control.

On an audiometer the volume control will most likely be labeled "Hearing Loss" and be scaled in units of "db." The frequency control will be labeled "Frequency" and be scaled in either "Hz" or "cps." One Hz is one cps. In addition, there will be switches for "right" and "left," possibly color coded to match the earphones. Finally, there will be a pulser switch to turn the tones on and off. Experiment with the controls to familiarize yourself with their functions. Then go to Step 4.

3. If you are using BIP's, there will be two of them in your testing set-up. One of them will have a dial taped in place. Ignore this BIP. The volume of the tone in the earphones may be adjusted with the "db" dial of the untaped BIP. The frequency of the tone may be adjusted with the "freq" dial of the untaped BIP. Next to the "freq" dial there is a slide switch. When the switch is down, the tone will be 10 times the indicated frequency on the dial. Experiment with the controls to familiarize yourself with their functions. Then go to Step 4.

4. Determine the subject's hearing thresholds for each ear for each of the following frequencies: 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 cps. Record the sound level in "db" of the quietest tone the subject can hear.

The subject should use hand signals to indicate whether or not the tone is heard.

The tester should doublecheck a particular hearing threshold (to make sure that the subject can actually hear the tone) by going from inaudible to audible and the reverse a couple of times. The tester should also vary the rhythm of the testing procedure so that the subject cannot anticipate the next move.

5. After one subject's hearing thresholds have been determined, the tester and subject should switch roles.

6. Each subject should graph his or her own audiometric data. Scale the graph as shown in Figure 2 on the following page. Use an X for each point that corresponds to a right-ear hearing threshold and an O for each left-ear hearing threshold.

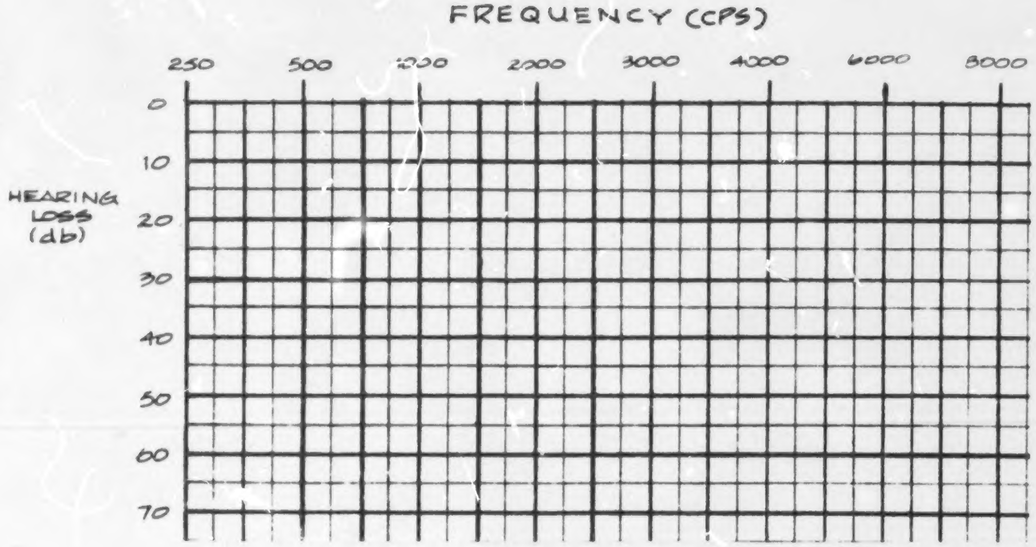


FIGURE 2

LABORATORY ACTIVITY 22: LOOKING INTO THE EAR, AND PERFORMING THE RINNE TEST

GENERAL INTRODUCTION:

This activity has two parts. In Part I you will visually examine the eardrum. In Part II you will perform a hearing test that compares a subject's sensitivity to sound by way of two routes--bone conduction and air condition.

PART I: LOOKING INTO THE EAR

INTRODUCTION:

In this activity you will make a model of an otoscope, an instrument used to look into the ear. In Part IC of the activity you will examine a student subject. The principal goal of this activity is to find and identify the main features of the eardrum. It is extremely important that you follow directions closely to avoid discomfort and possible mild injury to the subject.

PART IA: MAKING THE OTOSCOPE

The otoscope consists of 2 parts: a speculum and a magnifier with light source (Figure 1 following page). The speculum is needed because the external ear canal is not straight, and because it helps to "funnel in" the light beam so that the eardrum is light enough to be easily seen. The magnifier is needed because the eardrum is only about 10 mm in diameter and its features are too small to be seen easily with the naked eye.

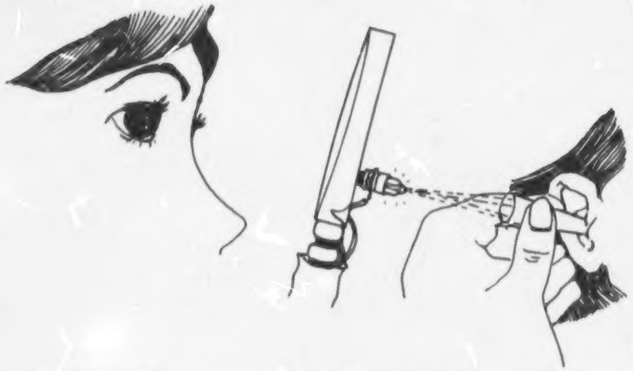


FIGURE 1: A speculum and lens-lamp.

MATERIALS:

- hand lens
- #222 flashlight lamp, with soldered lead
- white paper, medium weight
- white glue
- masking tape
- silicone rubber cement
- red ink pen
- black ink pen
- resistor, 10 to 15 ohms
- BIP

PROCEDURE:

1. Cut a pattern of paper according to the template below:

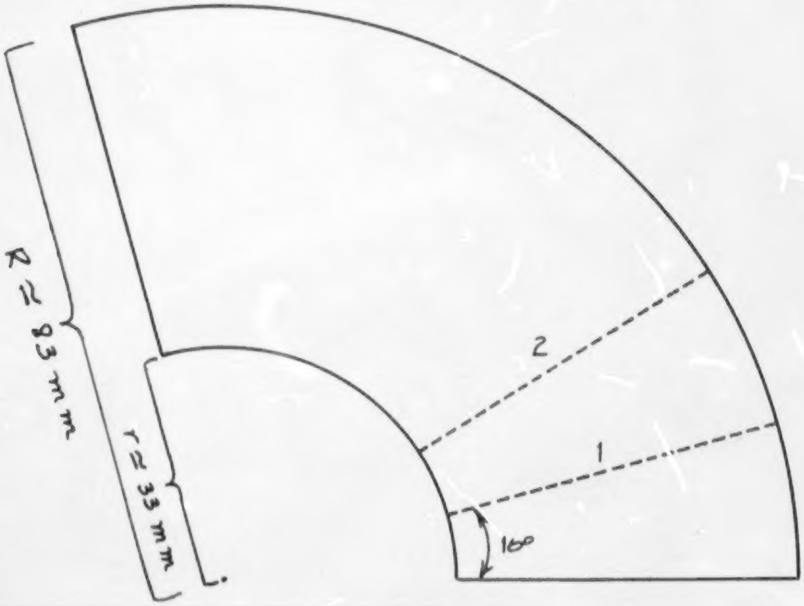


FIGURE 2: Template.

2. Attach a strip of tape as shown on the following page and then fold the paper in such a way that the first layer of the speculum is made. Be sure the edge of the pattern and Dashed Line 2 are lined up; otherwise, the speculum will be too large or too small.

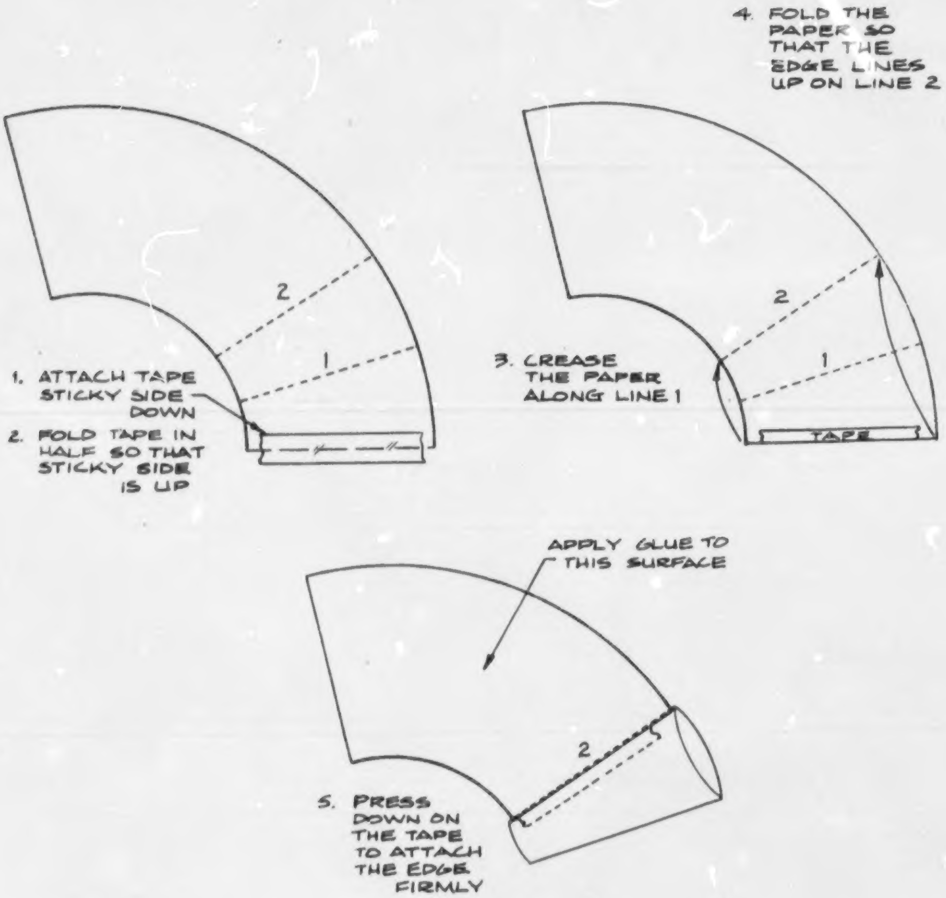

4. FOLD THE PAPER SO THAT THE EDGE LINES UP ON LINE 2
2
1
1. ATTACH TAPE STICKY SIDE DOWN
2. FOLD TAPE IN HALF SO THAT STICKY SIDE IS UP
2
1
3. CREASE THE PAPER ALONG LINE 1
TAPE
APPLY GLUE TO THIS SURFACE
2
5. PRESS DOWN ON THE TAPE TO ATTACH THE EDGE FIRMLY

FIGURE 3: Folding and gluing the paper speculum.

3. Now locate the surface to be wrapped (see third sketch of Figure 3). Cover this surface evenly with a thin layer of white glue.

4. Roll the glue-covered surface around the cone you formed in Step 2. Try to keep it as round as possible. Also, roll it snugly so that paper touches paper and there is no air space.

5. The finished speculum will consist of about 3 layers of paper. Until the paper dries, use a small strip of tape to keep the outer edge from pulling away from the layer underneath.

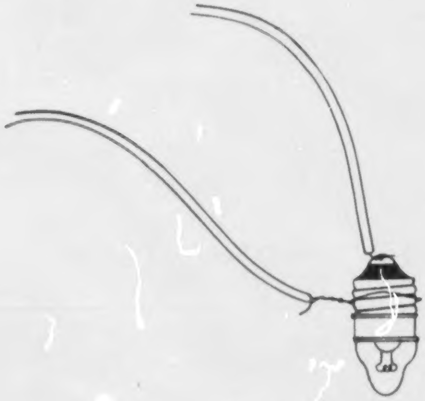


FIGURE 4: Connecting a second wire to the lamp.

6. Before putting the speculum away to dry, make it as round as you can. Trim the ends if necessary. The speculum will become fairly rigid once the glue dries. After that its shape can't be changed without weakening the wall. When dry, draw a black circle around the outside of the speculum 15 mm from the small end and a red circle 20 mm from the small end.

7. The flashlight lamp should have one BIP wire soldered to its tip. Twist a second wire of equal length around the threaded portion of the lamp (Figure 4).

8. Using tape, attach the lamp to a 2-to 3-inch hard magnifier. Be sure the lens is clean and grease free. Note that the lamp is placed slightly below center; looking through the center of the glass, you should be able to see past the lamp. The wires should form a "V" as shown in Figure 5.

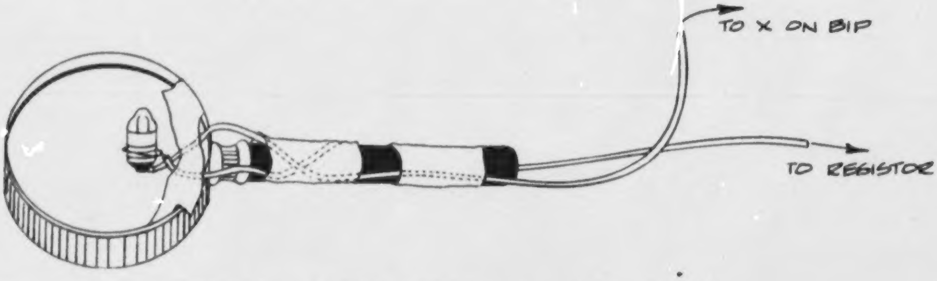


FIGURE 5: Otoscope (lens-lamp part).

9. Also tape the wires to the magnifier handle as shown in Figure 5.

10. The lamp should be perpendicular to the lens and tilted slightly toward the center.

PART IB: PRELIMINARY TESTING

1. Program the BIP T to U; insert one of the wires from the lamp into terminal X.

2. A 10- to 15-ohm resistor should be inserted in the other lamp lead. Insert this second lead into terminal S as shown in Figure 6. Connections to the resistor can be made using alligator clips or by twisting together bare wire ends. Do not insert the resistor directly into terminal S.

3. Turn the variable voltage control full counterclockwise (Figure 7, following page).

4. Plug in the BIP. The lamp should light but should not be any brighter than an ordinary small flashlight. If it is very bright, turn off the BIP immediately and recheck Steps 1 through 3.

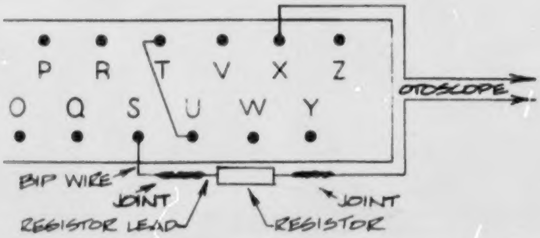


FIGURE 6: Programming the BIP.

5. Draw a circle about 10 mm in diameter with pencil and shade it light grey. This is a simulated eardrum.

6. Using the "otoscope," examine the circle through the magnifier. Notice that care is needed to position the lamp beam and magnifier to get the best view. Position your eye just barely above the lamp. You may need to reposition the lamp; slight changes in lamp position can be made without removing the tape.

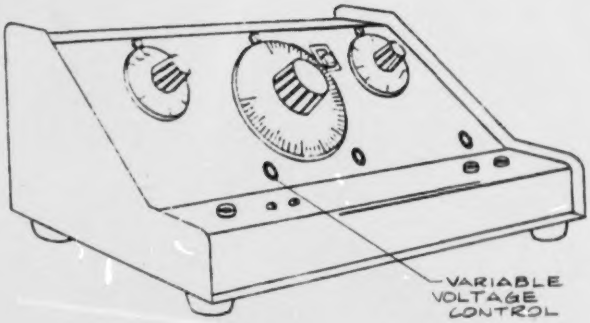


FIGURE 7: Location of the variable voltage control.

7. Now position the small end of the speculum about 10 to 15 mm from the circle. View the circle through the speculum. Notice that you can't see all of the circle at once, and you must move the speculum somewhat. When you view a real eardrum, the ear canal will not permit much movement of the speculum; but with proper technique you will be able to see all of the important features of the eardrum.

8. Be sure you master Step 7 completely before going to Part IC, because your subject will not be as quiet and patient as the grey circle!

PART IC: OBSERVING THE EARDRUM

BE CAREFUL. BE GENTLE. The paper speculum has been designed to be large enough so that it cannot be pushed too far into the average-sized ear. For safety's sake, the red circular band 20 mm from the small end should not be pushed beyond the opening of the external ear canal. The ear canal is sensitive, so the speculum may cause mild discomfort; pain is an indication of improper technique or some ear problem. After observing a demonstration by your instructor, you are ready to proceed in groups of three or more. One person is the subject, and one person is the safety monitor. Both the subject and the observer may be either seated or standing, whichever is more convenient.

PROCEDURE:

1. Grasp the upper part of the right ear with the left hand. Pull the ear upward and backward. This will straighten the ear canal. See Figure 8 on the following page.

2. Grasp the speculum with the right thumb and index finger. Slowly insert the speculum into the ear canal, using a rotating motion. Push gently. Do not use force. Ask the safety monitor to tell you when he can no longer see the black line, which means that the speculum is at least 15 mm into the ear canal.

3. DO NOT INSERT THE SPECULUM BEYOND THE RED LINE, EVEN IF IT CAUSES NO DISCOMFORT.

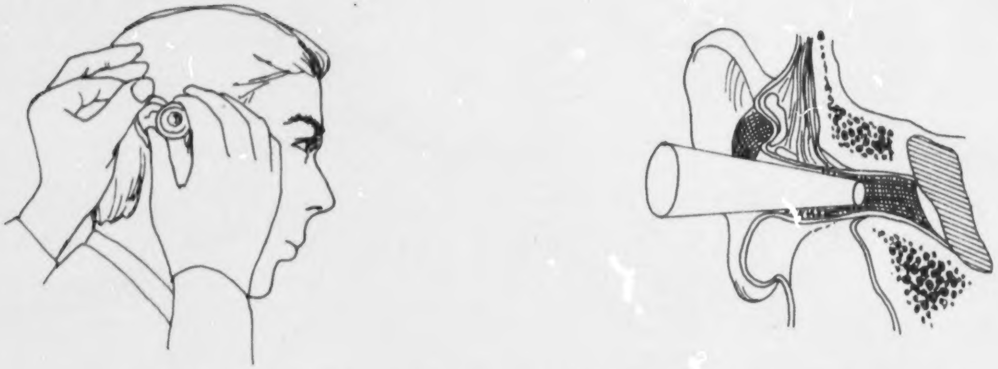


FIGURE 8: Insertion of the speculum.

4. Continue to insert the speculum as long as it inserts easily and causes no more than mild discomfort. Remind the monitor to tell you if the red line is about to disappear.

5. With the speculum inserted (Steps 2 and 4) release the part of the outer ear held by your left hand.

6. Grasp the otoscope with the left hand. Use the technique you practiced in Part IB, Steps 6 and 7. Position the otoscope and your line of vision in whatever way gives you the view of the eardrum. The eardrum will be about 10 mm beyond the tip of the speculum.

7. You will not see quite all of the eardrum at once because of a small shadow caused by the speculum, and because the tip is a little smaller than the drum. Tilt the speculum slightly in whatever direction gives the best view. Figure 9 shows the main features that can be seen. The eardrum is pale grey-blue except at "A" and "B," which appear almost white.

8. Try having the subject swallow while his mouth is closed and his nose is pinched shut. Watch the eardrum carefully during this time. What happens? Record your observations.

A-light reflection

B-middle ear bone

C-edge of eardrum

D-eardrum

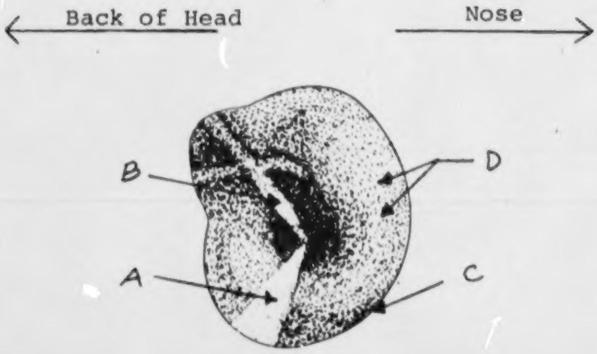


FIGURE 9: The ear canal.

PART II: THE RINNE TEST

INTRODUCTION:

Sound waves reach the cochlea (inner ear) by either of two routes. As described in Section 22, they may come in through the auditory canal and generate vibrations in the eardrum which are conducted to the oval window of the cochlea by means of the bones of the middle ear. This route is called "air conduction."

The cochlea is encased in the bones of the skull, and vibrations of the skull bones will cause vibrations of the inner ear fluid directly. Thus the sensation of hearing can be produced by this second route, called "bone conduction."

We hear our own voices by a combination of air and bone conduction while others (and tape recorders) hear us by means of air conduction alone. The lower frequencies are transmitted more easily in bone than in air. Therefore, our own voices seem lower pitched to us than to others, and we may be surprised at the higher pitch of our voices when we listen to ourselves on tape.

The existence of these two hearing pathways creates possibilities for the diagnosis of particular kinds of hearing disorders. Suppose a middle ear infection has damaged the bones of the middle ear while leaving the cochlea unharmed. Then bone conduction would be unimpaired, but air conduction would be less responsive. The Rinne Test is a technique used by audiologists to compare air and bone conduction.

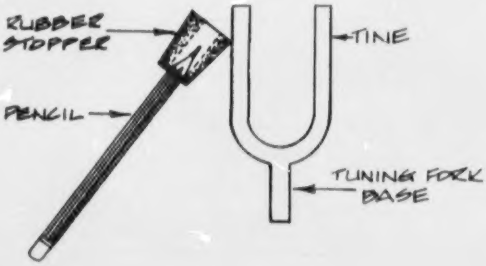
MATERIALS:

tuning forks--from one to 5 of different frequencies in the range 256 cps to 2048 cps

pencil stuck into the hole of a rubber stopper (the size of the rubber stopper is unimportant)

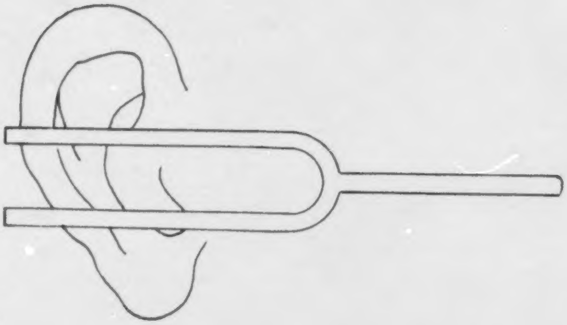
PROCEDURE:

1. The Rinne Test. Hold the tuning fork by the base. Set the tuning fork into vibration by striking one tine with the stopper-pencil mallet.



2. Place the vibrating tuning fork next to the subject's ear as shown on the following page. It is important that the tines be pointing backward and the base forward.

3. When the patient signals that she or he can no longer hear the sound produced by the tuning fork, the examiner quickly places the base of the tuning fork against the bone immediately behind the outer ear. Then the subject indicates whether she or he can still hear the tone. Normal subjects will hear the tone better by air conduction rather than by bone conduction because normally the sound is amplified by the middle ear mechanism. Therefore, a normal subject will not hear the tone when the tuning fork is placed in contact with the bone.



4. The reverse Rinné Test. In this step the order of Steps 2 and 3 is reversed. First the base of the tuning fork is placed against the bone. When the subject indicates that she or he can no longer hear the tone, the tuning fork is moved into the air conduction position of Step 2. Subjects with normal hearing will again hear the tone because normal ears are more sensitive to air conduction than bone conduction.

5. Record your results. What is the frequency of the tuning fork? Was the subject's air-conduction sensitivity better than bone-conduction sensitivity for each ear?

DISCUSSION QUESTIONS:

1. Suppose a subject is known to have hearing loss and is more sensitive to air conduction than to bone conduction. Does this combination of test results indicate that the hearing loss is due to the air-conduction mechanism (i.e., auditory canal--eardrum--middle ear bones) or the cochlea (i.e. the inner ear where the sensory-neural mechanism is located)?

2. Suppose a subject who is known to have hearing loss is more sensitive to bone conduction than to air conduction. What does this combination of test results indicate about the location of the subject's impairment?

LABORATORY ACTIVITY 23: SPEED OF SOUND--RESONANT METHOD

INTRODUCTION:

In this activity you will calculate the speed of sound from measurements made on a resonating air column. Any enclosed column of air can be made to resonate. When air resonates, standing longitudinal waves are set up. In a standing wave, the wave travels back and forth on itself with a minimum loss of energy.

The conditions needed to produce resonance (standing waves) in a column of air are critical. The length of the air column must be adjusted to the point where very little energy is lost when the wave is reflected back on itself. When this point is reached, the column of air will resonate. The wavelength is found by making use of the fact that the length of the resonant air column is an odd multiple of quarter wavelengths. The wavelength is then multiplied by the frequency to give the speed of sound ($s = f\lambda$).

MATERIALS:

resonant apparatus
tuning fork, 512 cps (or other)
meter stick
2 rubber bands
beaker, 250-ml (or larger)
rubber stopper, one hole
stethoscope
thermometer

PROCEDURE:

1. Assemble the resonant apparatus as shown in Figure 1. Clamp the tuning fork so that the bottom tine is 0.5 ± 0.2 cm above the end of the resonant tube.

2. Pour 300 ± 50 ml of water into the funnel.

3. Find the first resonant point. Strike the tuning fork with the rubber mallet (Figure 2, following page). Move the funnel up or down to change the water level in the resonant tube. Find a water level where the sound is loudest. This is the first resonant point. It is almost $\frac{1}{4}$ wavelength ($\frac{\lambda}{4}$) from the top of the tube. Mark the point with a rubber band. Measure and record its position, ± 0.1 cm, from the top of the tube.

4. Estimate the location of the second resonant point. This point is difficult to locate.

a. Measure the inside diameter (in cm) of your resonant tube. Then multiply this length by .4.

b. Add the result of Step 4a to the approximate quarter wavelength of Step 3.

c. Multiply the sum of Step 4b by 3. This length from the top of the tube should be the approximate location of the second resonant point.

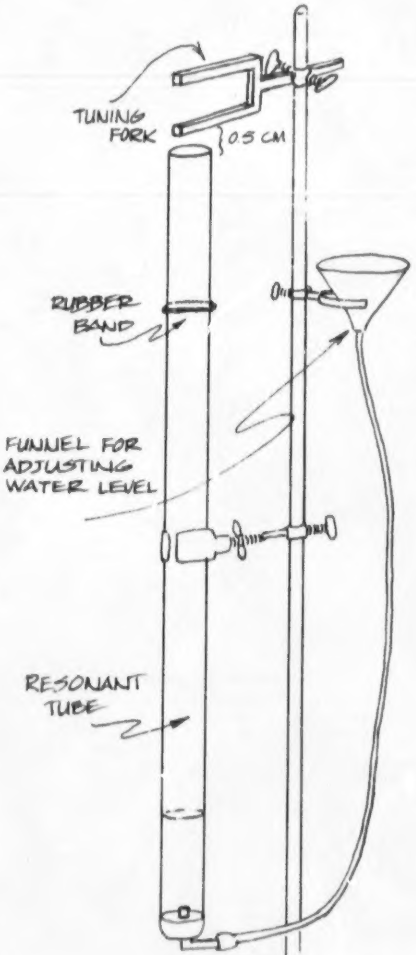
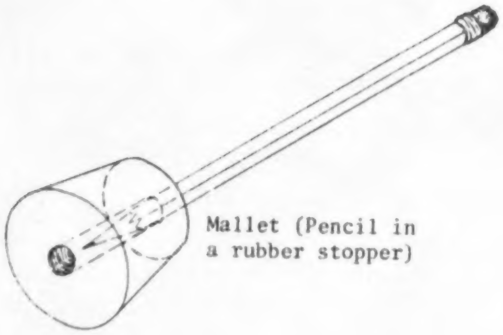


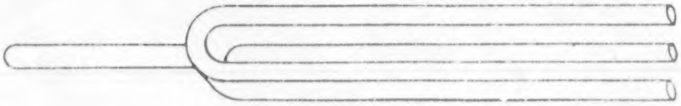
FIGURE 1: The resonant tube apparatus.

5. Locate the second resonant point. It will not be as strong as the first point. It is perhaps easiest to locate when the tone is crossing the threshold of hearing. As the water level passes the resonant point, the loudness of the tone will go from inaudible to audible and back to inaudible.

Use the stethoscope. Hold the stethoscope beside the tuning fork and point the bell downward as much as possible. Be sure that the bell does not touch the tube.



Mallet (Pencil in a rubber stopper)



Tuning Fork (à la Escher)

FIGURE 2: The rubber mallet and an unusual tuning fork.

The person listening through the stethoscope should also hold the funnel and move the water level up and down. Others can do such things as strike the tuning fork when requested and mark the location of the resonant point.

6. If your tuning fork has a frequency of 456 cps or more you may be able to locate a third resonant point. If your tuning fork's frequency is less than 456 cps go on to Step 9.

7. Measure the distance between the first and second resonant points, then measure down beyond the second resonant point an equal distance. This should be the approximate location of the third resonant point.

8. Find the third resonant point. Use the techniques described in Step 5.

9. Determine and record the wavelength of the tone produced by your tuning fork.

If you were able to locate a third resonant point, the wavelength (λ) will be the distance between the first and third resonant points.

Otherwise, λ will be twice the distance between the first and second resonant points.

10. Calculate the speed of sound in air. The speed is equal to the frequency (f) times wavelength (λ) (i.e., $s = \lambda f$).

The speed of sound in air depends upon the temperature of the air--the warmer the air, the faster the sound. Sound travels 0.6 m/sec faster for each °C rise in temperature. Measure the temperature of the air in your room and then calculate the speed of sound in air at 20 °C.

$$S_{20^\circ} = S_{\substack{\text{room}\\\text{temp.}}} - \left[\left(\substack{\text{room}\\\text{temp.}}\right) - 20^\circ\right](.6)$$

DISCUSSION QUESTIONS:

1. The auditory canal is known to resonate in the range of 3,000 to 4,000 cps. Suppose that a particular auditory canal resonates at 3,300 cps. A standing quarter wave is set up in the canal. Calculate the length of the canal. (Assume that the first resonant point is one quarter wavelength from the entrance to the canal, and use $s \approx 330$ m/sec).

2. The vocal tract from your vocal cords to your mouth may be thought of as an unevenly shaped air-filled tube, open at one end (your mouth) and closed at the other (your vocal cords). It is about 16.5 cm long.

   a. At what frequency would a standing $\frac{1}{4}\lambda$ be set up in a uniform circular column of air 16.5 cm long? (Make the same assumptions as in Question 1.)

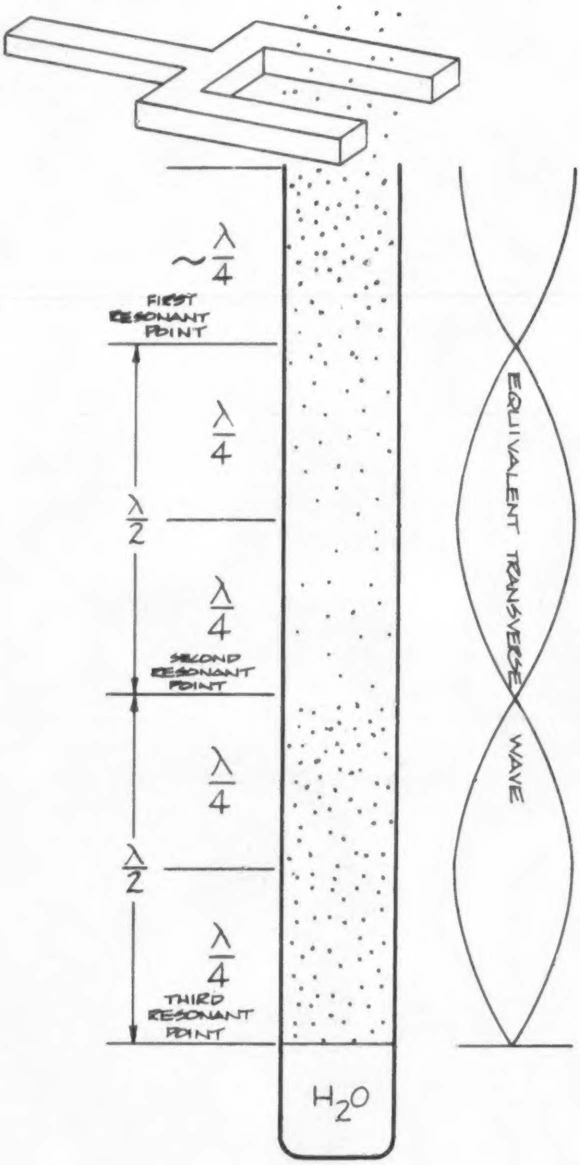
   b. At what frequency would a standing $\frac{3}{4}\lambda$ be set up?

   c. At what frequency would a standing $\frac{5}{4}\lambda$ be set up?

LABORATORY ACTIVITY 24: STANDING WAVES IN STRINGS

INTRODUCTION:

Standing waves are very important in any study of waves. In hearing, it is the location of an antinode in the basilar membrane which tells us the pitch of a sound. In speech, standing waves are generated in the vocal cords. The amplitude of these waves governs the loudness of speech, and the frequency determines the pitch. In this activity you will explore various factors which affect the pitch of sounds generated by the larynx. This information will help you understand changes that occurred in your voice as you grew up and how you can change the pitch of your voice as you please.



$\sim\frac{\lambda}{4}$
FIRST RESONANT POINT
$\frac{\lambda}{4}$
$\frac{\lambda}{2}$
$\frac{\lambda}{4}$
SECOND RESONANT POINT
$\frac{\lambda}{4}$
$\frac{\lambda}{2}$
$\frac{\lambda}{4}$
THIRD RESONANT POINT
H_2O
EQUIVALENT TRANSVERSE WAVE

FIGURE 3: First three resonant lengths for a given tuning fork.

In this activity you will use a BIP and speaker to generate standing waves in a stretched string.

PART I: THE EFFECT OF TENSION, LENGTH AND LINEAR DENSITY ON THE VIBRATIONAL FREQUENCIES OF STRETCHED STRINGS

MATERIALS:

BIP
speaker, permanent magnet type, 4 to 16 Ω impedance
short programming wire, stripped on both ends
2 long (~40 cm) wires, stripped on both ends
2 alligator clips
meter stick or other measuring device
2 paper clips
2 C-clamps or equivalent
balance
weight kit
pair of pliers (optional)
assorted strings, cords and wires of various lengths and linear densities

PROCEDURE:

1. One person should assemble the equipment as shown in Figure 1, while another does Step 2 and a third does Step 3.

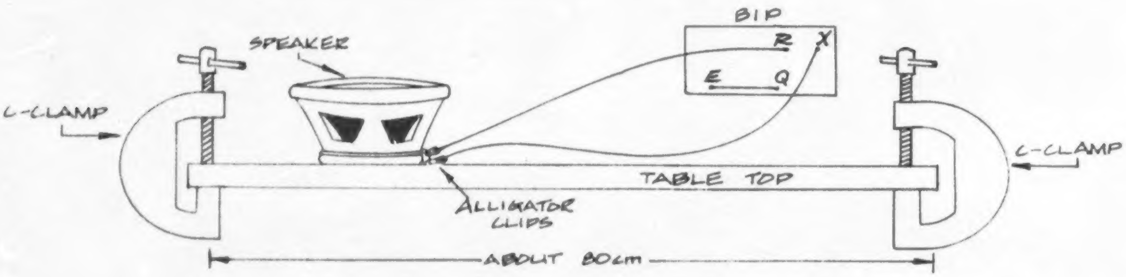


FIGURE 1: Initial arrangement of BIP, clamps and speaker.

2. Measure and cut off 1-meter lengths of two kinds of string or other kind of material. Then weigh them.

Record three pieces of information for each item (1) a description (e.g., "20-lb test monofilament fishing line"), (2) its length (1 m), and (3) its mass.

The mass of a 1-meter length of string is numerically equal to its linear density in g/meter.

3. Straighten a paper clip and then bend it as described below. Use pliers if they are available.

a. Bend a "foot" on one end of the straightened clip (Figure 2). The foot should be approximately at a right angle with the rest of the length of the clip. When completed, the rest of the straightened clip should balance on the foot.

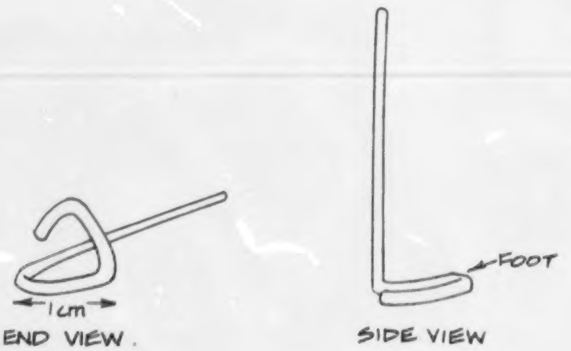

1cm
END VIEW
FOOT
SIDE VIEW

FIGURE 2: Views of the foot.

b. Bend an "N" shape on the other end of the rebent clip (Figure 3). You should try to make the straight sections between the bends as short as possible. It is important to leave as much distance as possible between the foot and the N-shape.

When you are finished, the entire structure should balance on the foot. You may have to twist the N-shape around so that it is directly above the foot.

4. Use a half hitch to produce a loop on each end of each string. The loops should not be over 5 cm long when pulled tight.

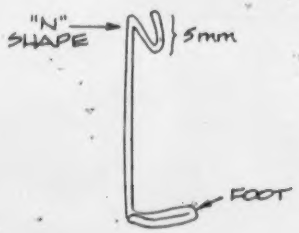

"N" SHAPE
5mm
FOOT

FIGURE 3: The location and size of the N shape on the rebent paper clip.

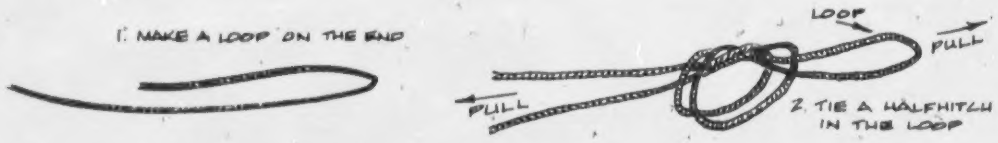

1. MAKE A LOOP ON THE END
LOOP
PULL
PULL
2. TIE A HALFHITCH IN THE LOOP

FIGURE 4: Tying a half hitch.

5. Arrange a string (or whatever), the rebent paper clip, speaker and 500-g weight as shown in Figure 5.

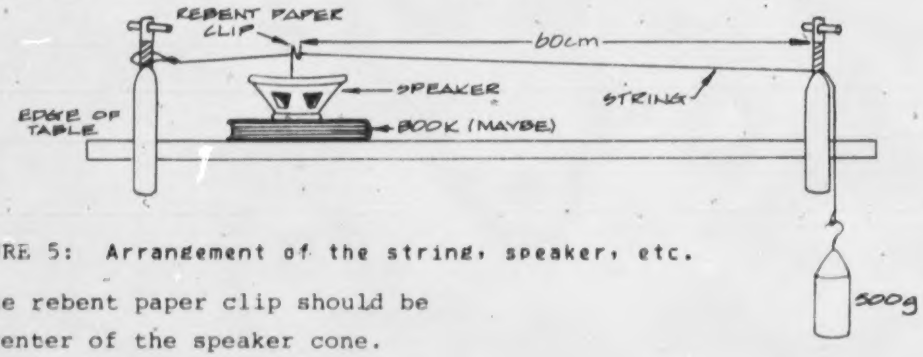

REBENT PAPER CLIP
60cm
SPEAKER
STRING
EDGE OF TABLE
BOOK (MAYBE)
500g

FIGURE 5: Arrangement of the string, speaker, etc.

The foot of the rebent paper clip should be positioned in the center of the speaker cone.

The tension in the string should hold the rebent paper clip firmly in place. If it doesn't, raise the speaker by placing books underneath it until the wire is held in place.

Move the right clamp or the speaker until the distance between the paper clip and the point where the string contacts the right clamp is as close to 60 cm as you can make it. From now on we will refer to the distance from the paper clip to the right clamp as the effective length of the string.

6. Plug in the BIP. The upper left dial labeled "db" controls the volume of the tone. The dial labeled "freq" in the upper right controls the frequency. The slide switch just to the left of the frequency dial should be in the up position (Figure 6).

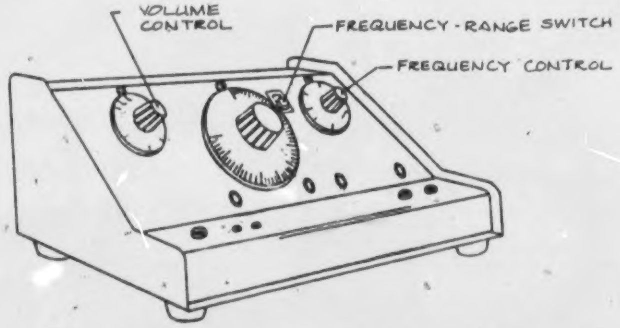


FIGURE 6: The location of the volume and frequency controls and the slide switch.

7. Turn the volume dial to maximum and vary the frequency. At certain frequencies standing waves will be set up in the string.

Sometimes the vibration of the string will be so strong that the paper clip will shake loose. When this happens there are a couple of things you can do. Either put more books under the speaker to increase the force holding the foot against the speaker, or tie a slip knot in the string, hook the top of the paper clip into it and then pull the knot tight on a leg of the "N" on the paper clip.

8. Practice generating standing waves of different wavelengths and amplitudes by varying the frequency and volume controls.

9. From time to time things happen which affect our ability to speak. We may get laryngitis and "lose our voice," or we may develop "singer's polyps" which are little lumps on the vocal cords. We can model what happens at such times by connecting a paper clip to the string.

Attach a paper clip on the string and attempt to generate standing waves in it. Record your observations.

10. Remove the paper clip.

11. Determine the lowest BIP frequency required to produce a clean standing wave. For materials with linear densities in the neighborhood of 1 g/meter or greater, the pattern will be a full standing wave, although it may look like a half wave at full volume. Reduce the volume until it is just over the amount required to excite the string. Then the pure standing wave pattern will become clearer. (The frequency required to produce a full standing wave is called the second harmonic. The frequency of a half standing wave is called the first harmonic or the fundamental. Sometimes the second harmonic will excite the string's fundamental frequency and the string will vibrate at both frequencies simultaneously.)

When you have the string resonating at the lowest obtainable BIP frequency, divide a piece of paper into two columns and record these things:

a. the type and effective length of string (e.g., "20-lb test nylon monofilament line--effective length 60 cm.");

b. "f" or frequency, as close as you can estimate from the dial;

c. "λ" or wavelength. Remember that the distance between two successive nodes is $\frac{\lambda}{2}$;

d. the mass hanging on the string (m);

e. the linear density in grams per meter (See Step 2).

12. Increase the frequency until the next standing wave pattern is obtained. It will have one more node and one more antinode. Once again record f, λ, m and linear density.

13. Increase the frequency gradually and record the same four pieces of information about each successive standing wave pattern until the next one is not detectable.

14. Hang a 2-kg mass on the string and repeat Steps 11 through 13.

15. Change the string and repeat Steps 11 through 14.

16. Halve the effective length of string to 30 cm and repeat Steps 11,12,13 and 15.

17. Change the variables as you please. For example you may want to stretch a string halfway across the room or try to vibrate an electrical extension cord. Record all the details asked for above.

PART II: BEATS AND HARMONICS IN STANDING WAVES

MATERIALS:

- set-up for Part I
- second BIP
- alligator clip

PROCEDURE:

1. Program the two BIP's as shown in Figure 7 and then plug in both of them.

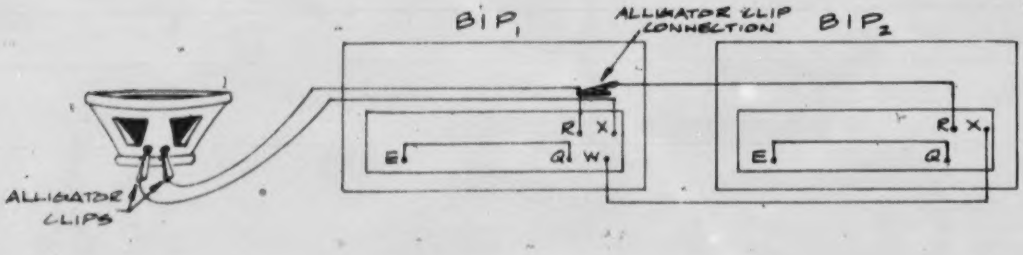


FIGURE 7

2. Turn the volume control of BIP_2 to zero and use BIP_1 to set up a standing half wave.

3. Reverse Step 2. Turn BIP_1 down and set up a standing half wave with BIP_2.

4. Turn both BIP's to maximum volume.

5. By varying slightly the frequency of one BIP, various beat patterns may be observed.

6. Turn one BIP to zero volume and change the frequency of the other one so that a full standing wave is set up.

7. Turn the other BIP back up. You will probably have to adjust the frequency of one of the BIP's to minimize the beat effects. With careful adjustment of the BIP's and close observation of the string, you should be able to observe both vibrational modes occurring in the string simultaneously.

DISCUSSION QUESTIONS:

1. In general, the longer the string, the (lower, higher) the fundamental frequency.

2. As we grow from small children to adults, the length of our vocal cords increases. What general effect will this have on the pitch of our voices?

3. The theoretical formula which is supposed to predict the fundamental frequency (f) is

$$f = \frac{1}{2L}\sqrt{\frac{F}{d}}$$

where L = the effective length of the string
F = the tension in the string
d = the linear density of the string

This formula predicts that if the effective length of the string (i.e., from driven point to clamp) is cut in half, then the fundamental frequency will double (all other variables remaining the same). Did you observe this? Refer to data that you collected to confirm or deny the prediction.

4. In general, when the tension on a string is increased, the fundamental frequency (increases, decreases).

5. Suppose we increase the tension on our vocal cords. What effect will this action have on the sound produced? Explain.

6. Another prediction of the formula of Question 3 is that if the tension in the string is quadrupled, the fundamental frequency should double (all other variables remaining the same). What did you observe? Did it more than double, less than double? Refer to your data to support your answer.

7. In general, the greater the linear density of the string, the (greater, smaller) the fundamental frequency (all other variables remaining the same.

8. One effect of secondary sex changes which occurs at puberty is a thickening of the vocal cords in males. What effect will this have in general? Explain.

9. Another prediction of the formula is that an increase in the linear density of the string will result in a decrease in the fundamental frequency and vice versa (all other variables remaining the same). Did you observe this pattern? Refer to your data to support your answer.

10. Theoretically harmonics in stretched strings should occur at whole number multiples of the fundamental frequency. Did you observe this pattern? Refer to data that you collected to support your answer.

LABORATORY ACTIVITY 26: THE WAVELENGTHS OF DIFFERENT COLORS

INTRODUCTION:

A diffraction grating is somewhat like a phonograph record--they both have a lot of grooves per inch. The phonograph record might have 200 grooves per inch (you can see them), while a diffraction grating might have thousands of grooves per inch (you cannot see them).

When light waves pass through the grooves of a grating, they interfere with each other. They produce no light at some points and bright light at others. The regions of bright light occur only at certain locations which depend upon the distance between the lines (grooves) of the grating, the frequency and wavelength of the light and the distance to the screen.

In this activity, you will use a diffraction grating to determine the wavelength and the frequency of different colors of light.

MATERIALS:

diffraction grating
light source
cardboard rectangle
meter stick
tape
scissors
2 ring stands, small
2 clamps, buret
BIP with accessory light
protractor

PROCEDURE:

1. (One student can do Steps 1 and 2 while another does Step 3.) Construct a light shield and slit for the diffraction grating as follows. Cut as narrow a slit as possible in the center of the long side of the piece of cardboard. The slit should be about 5 cm long and on the order of 1 mm wide. Darken the region around the edges of the slit with a pencil held flat.

2. Tape the diffraction grating over the darkened side of the slit. The lines (rulings) of the grating should be parallel to the slit. It is sometimes difficult to tell which way the grooves run. If you have this problem, just tape the slide onto the grating so that one side of the grating is even with the bottom. In Step 7 you will check to see whether this orientation is correct or not. Be careful not to get fingerprints on the diffraction grating.

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3. Attach two strips of tape to the table for recording various locations. Arrange the pieces of tape as shown in Figure 1. Pencil a cross in the center of the 10-cm strip.

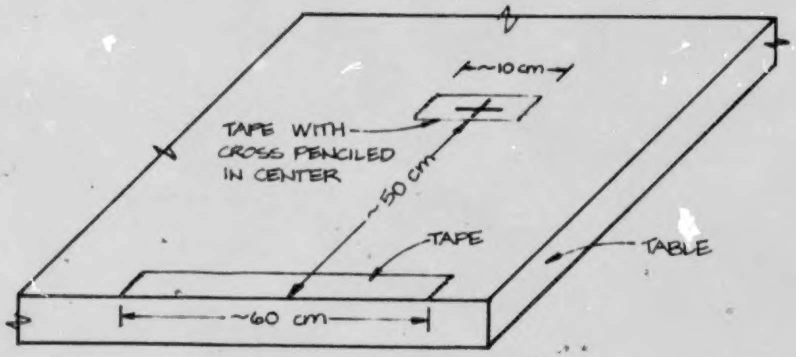

~10 cm
TAPE WITH CROSS PENCILED IN CENTER
~50 cm
TAPE
TABLE
~60 cm

FIGURE 1: Initial placement of tape.

4. Arrange the equipment as shown in Figure 2.

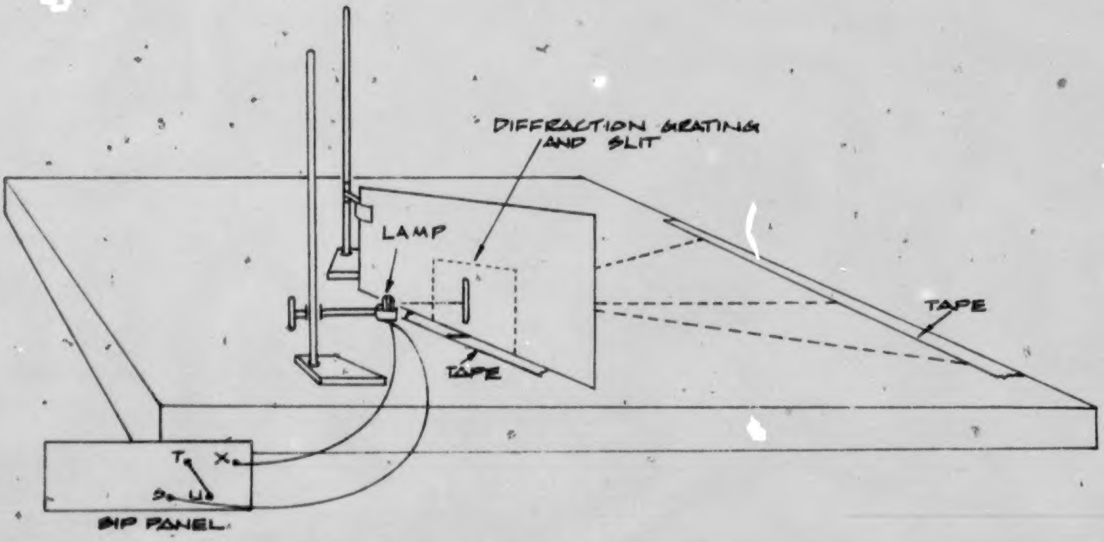

DIFFRACTION GRATING AND SLIT
LAMP
TAPE
TAPE
T
X
S
U
BIP PANEL

FIGURE 2: Initial arrangement of equipment.

5. Before turning on the lamp (by plugging in the BIP) rotate it so that the filament is perpendicular to the light shield. The filament is very small and hard to see, but its two supports may be lined up as shown in Figure 3. Tighten the clamp to hold the lamp in position and turn on the BIP. Your teacher will show you how to adjust the brightness of the lamp.

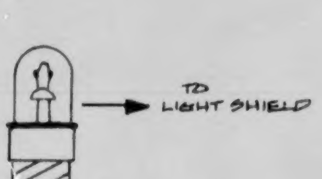

TO LIGHT SHIELD

FIGURE 3: Orientation of the lamp.

6. Position the slit and screen so that the slit is directly over the penciled cross on the piece of tape. Then use tape to hold the screen in position.

7. Now you may be ready to begin your observations. By placing an eye (shut one eye) at the locations shown in Figure 4, you should be able to see a spot of light on the diffraction grating. In the middle position you should be able to see the lamp. If you can't, reposition the lamp until you can.

Off to either side, you should be able to see different colors. If you can't, the grooves on your diffraction grating are horizontal instead of vertical. Take the grating off, rotate it 90° and refasten the grating to the slit.

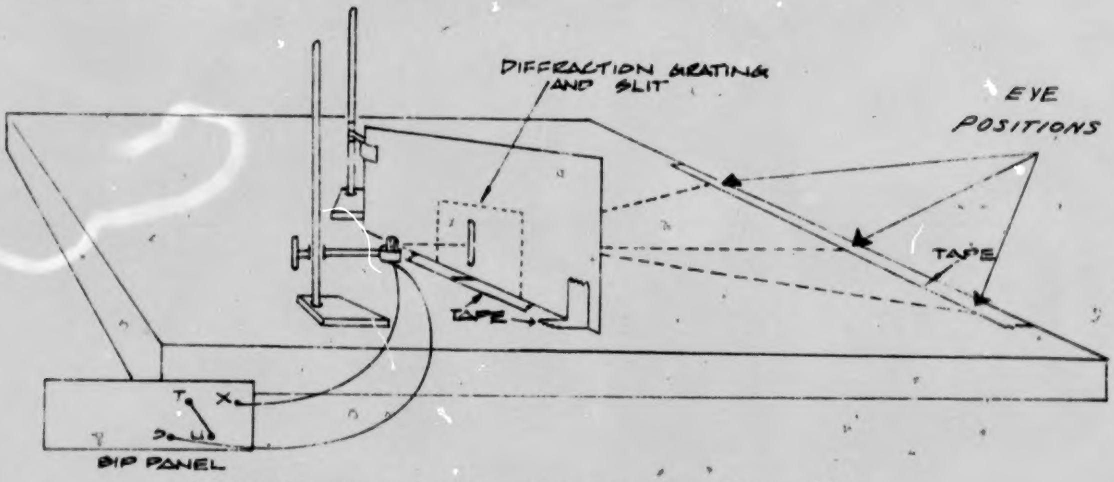


FIGURE 4: Eye positions to observe diffraction.

8. Is the slit still over the cross? If not, readjust the cardboard screen.

9. Now you are ready to begin your observations. Notice that as you move outward from the center position, you see a sequence of colors. What is the sequence? Record five colors that you see in the sequence that you see them.

10. Make marks on the tape which correspond to the five colors of Step 9. You and your lab partners should agree on the same five colors.

To make the marks, first move your eye into position to see a particular color. Then move your pencil so that it is between your eye and the slit. Label the mark on the tape for the corresponding color, i.e., "Y" for yellow and so forth.

11. Make a mark on the tape corresponding to the middle line. This was left for last because the afterimage of the middle line would interfere with seeing the colors in Step 9.

12. Move the screen, slit, grating, BIP-light, etc., away from the penciled cross on the piece of tape.

13. Prepare to position the protractor to measure θ. Place a piece of tape about 10 cm long next to the cross and running toward the mark for the middle line on the long piece of tape (Step 11). Next, line up the meter stick between the cross and the mark for the middle line. When the meter stick is in position draw a line on the new piece of tape. When this step is done, your table top should look like Figure 5.

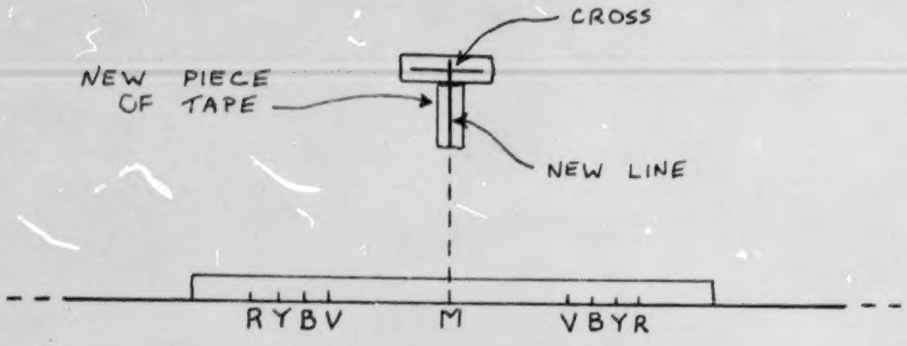


FIGURE 5: Top view of situation after Step 13.

14. The angles corresponding to the different colors may now be measured. Tape a protractor on the table top so that its base is on the line drawn in Step 12 and its center point is on the cross.

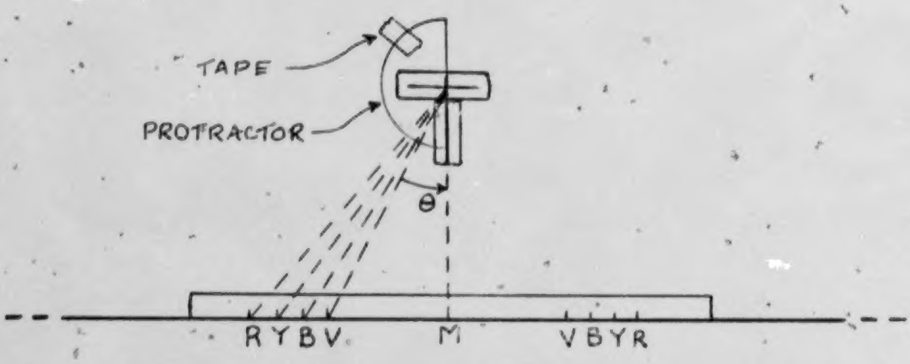


FIGURE 6: Position of the protractor for measuring the angles.

15. By lining up the center mark on the protractor and the marks for the colors with a meter stick, you can measure the angles. Measure the angles and record them. Be sure to indicate the color that each angle corresponds to.

16. Rotate the protractor 180° and repeat Steps 14 and 15.

17. A label somewhere on the diffraction grating will state how many lines per cm (or inch) are on the grating. From this information it is possible to calculate the spacings of the lines. Use dimensional algebra to calculate the spacing in cm. (If this step is not clear, review Problem Set 26.)

18. For a particular color, the wavelength may be calculated from the formula $\lambda = d \sin \theta$, where λ, d and θ are described in Figure 7 on the following page.

Calculate λ for all colors. First, find an average value for θ from the right and left measurements of θ for a particular color. Second, find $\sin \theta$ in the Table of Trigonometric Functions at the end of the Mathematics Text. Round $\sin \theta$ to two digits, then multiply by d. State your answer in nm.

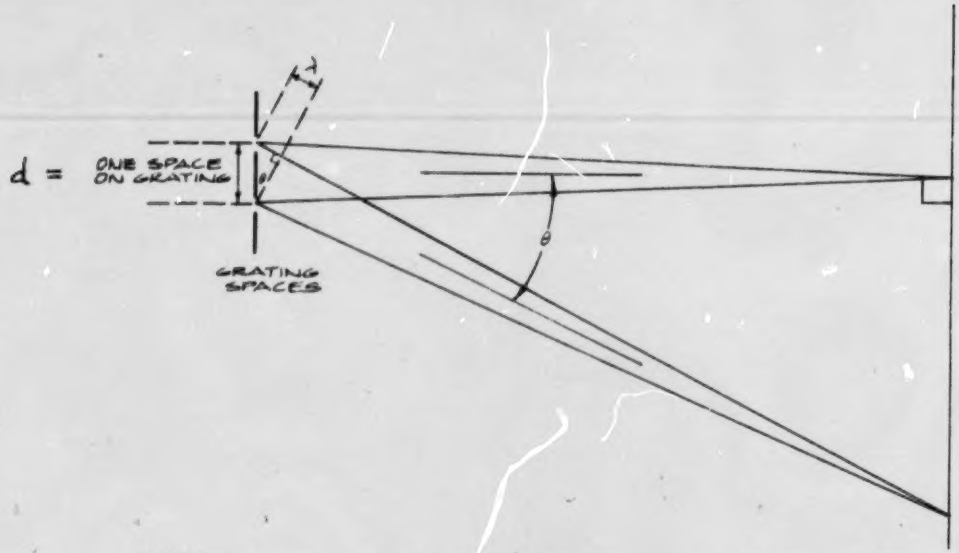


FIGURE 7: λ (in nm) = grating spacing (in nm) · sin θ

DISCUSSION QUESTIONS:

1. The size of the smallest object that may be seen with a light microscope is limited by the wavelength of light. Nothing smaller than one wavelength may be seen. What color of visible light should be used to achieve the greatest possible magnification with a visible-light microscope?

2. "Infrared" is the term used to describe light beyond red in the spectrum. "Ultraviolet" is the term to describe light beyond violet in the spectrum. Which light has the shorter wavelength? State the maximum or minimum wavelengths as appropriate for both kinds of light.

3. Although both infrared and ultraviolet light are ordinarily invisible, there are techniques to convert these kinds of light to visible frequencies. Which kind of light would you expect to be used to increase the magnifying power of light microscopes?

4. The speed of light is about 3×10^8 meters per second. Calculate the frequency of green light and of blue light.

LABORATORY ACTIVITY 27: WORKING WITH COLOR

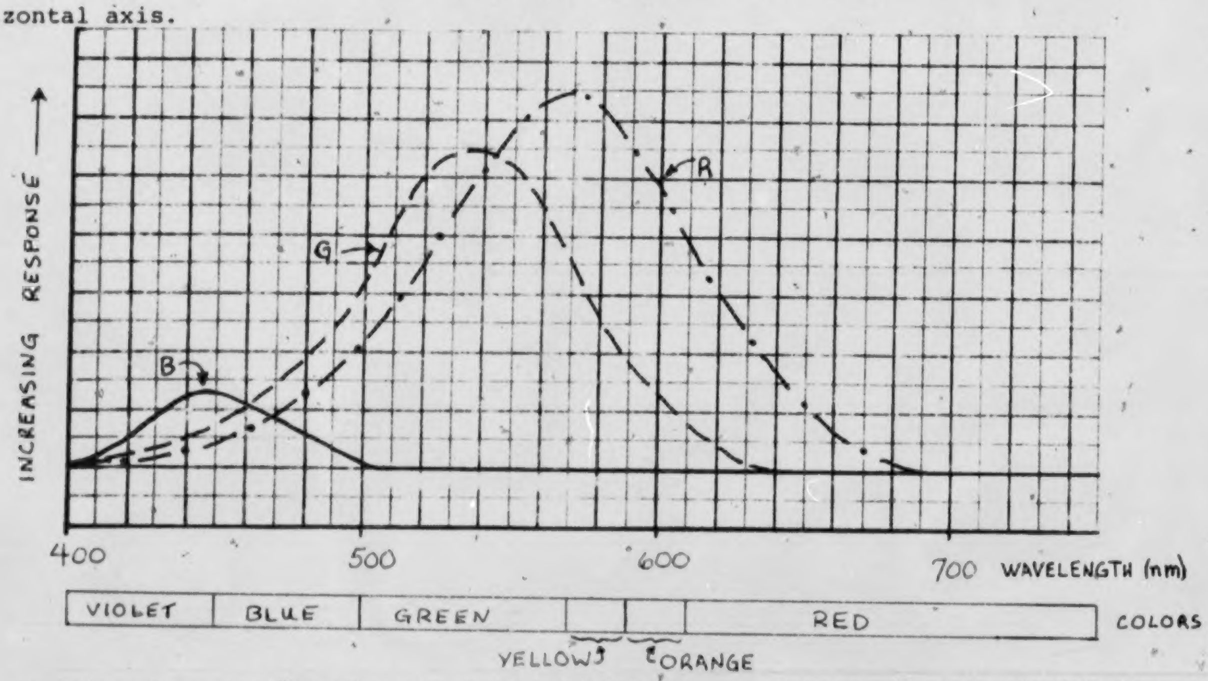
GENERAL INTRODUCTION:

In Laboratory Activity 26 you related color to the wavelength of light. As you discovered, the eye sees wavelengths between about 400 nanometers (violet) and 700 nanometers (red) and is most sensitive to wavelengths around 550 nanometers (yellow-green). In this activity we will be concerned with the perception of color and some of the properties of colored filters.

In Part I you will determine what wavelengths of light are transmitted by transparent filters of several different colors. In Part II you will be asked questions about the colors you see when you use the filters in various ways. You will need information from Part I to obtain correct answers in Part II. In addition, you will need the basic information about the perception of color which follows in this introduction.

Later in this unit you will study the anatomy of the eye in some detail. What you need to know now is that the back of the eye (the retina) contains three kinds of special color receptors called "cones." The three types of cones respond differently to light of any given wavelength. These tiny cones are very close together, so that even a small point of light falling on the retina will stimulate many cones. The responses of the cone receptors are then transmitted to the brain's visual center. The brain somehow fuses the information that it receives from the cones, with the result that we see color or white, depending upon how much each receptor is stimulated.

The differences among the responses of the three types of cones are illustrated in the following diagram. Each curve on the graph shows the intensity of the response of one type of cone (B, G or R) to light of the wavelengths indicated on the horizontal axis.



In Laboratory Activity 26 you used a diffraction grating to break white light up into wavelengths that you could see separately as bands of different colors. When you saw green, the wavelength of light was a narrow band of light centered at about 525 nm. From the graph, you can see that light of this wavelength will stimulate the G receptors most strongly, R receptors less strongly and B receptors least strongly. When these three responses are relayed to the brain, they are fused and we perceive the color we call green.

Light with a wavelength of about 450 nm will stimulate B receptors most strongly, R receptors less strongly and G receptors least strongly. The color we "see" is blue-violet. If the retina is stimulated by light of many wavelengths at the same time (such as the light that comes from a fluorescent lamp) we see no "color" at all, but see "white."

MATERIALS:

diffraction grating set-up (from Laboratory Activity 26)
4 color filters--blue, green, yellow and red

PART I: ANALYZING COLOR FILTERS USING A DIFFRACTION GRATING

INTRODUCTION:

To obtain bands of light of known wavelengths you will use the same diffraction set-up that you used in Laboratory Activity 26. By viewing bands of light of known wavelengths through color filters you will be able to determine which wavelength of light each filter transmits.

When you set up the diffraction grating, follow the earlier procedure exactly. Make marks on the tape at 430 nm (violet), 480 nm (blue), 530 nm (green), 570 nm (yellow), 610 nm (orange) and 660 nm (red). Label each mark with the wavelength. If you have trouble getting deep, clear colors, check to see that the filament of the lamp is positioned correctly in relation to the slit. For Steps 1 through 4 of the procedure make each observation as follows.

- Position your eye directly above one wavelength marking so that you get a clear view of the light.
- Without moving your head or eye, place the color filter in front of your eye.
- View the colored light coming from the diffraction grating through the color filter.
- Estimate the amount of light coming through the color filter as bright, dim or almost invisible.
- Using the same color filter, repeat this observation at each of the six wavelength marks (430 nm, 480 nm, 530 nm, 570 nm, 610 nm, and 660 nm).
- Record your results for use in Part II.

Observations are best made in a dimly lit room.

PROCEDURE:

1. With the red color filter, observe the appearance of light at each of the six wavelengths noted above. Make your own observations and compare them with the observations of others in your group. If you are getting comparable results, proceed with the next step. If not, recheck your set-up carefully. Remember that at the 660-nm mark on the tape the light should look red, at the 530-nm mark it should look green, etc.

2. Repeat the observations in Step 1, but with the yellow color filter. How does the yellow filter differ from the red filter? (1)

3. In a like manner, repeat your observations with the green filter. How does the green filter differ from the yellow filter? (2)

4. Finally, repeat your observations with the blue filter. How does the blue filter differ from the green filter? (3)

PART II: Analyzing Color Filters in White Light.

INTRODUCTION:

In Part I you determined the wavelengths of light that are transmitted through filters of certain colors. In Part II you will observe a source of white light (such as a fluorescent lamp) through a color filter or combination of filters. You should be able to explain the results of your observations on the basis of the information provided in the Introduction to this Activity, together with your own observations from Part I. Even if you aren't sure, speculate on the answers to each question before going on to the next step.

PROCEDURE:

1. Observe a source of white light through the yellow filter. In Part I you should have determined that the "yellow" filter actually transmits green, orange and red as well as it does yellow light. How can you explain the fact that this filter appears to your eye as yellow? (4)

2. Observe white light through the yellow and blue filters together. How do you explain that you now see green? (5)

3. Observe white light through the green filter. From Part I you observed that the green filter transmitted blue and yellow light as freely as green light. How do you explain the fact that this filter appears to your eye as green? (6)

4. Can you come to any conclusions as to the brain's perception of color from the results of Steps 2 and 3? (7)

5. Observe white light through the green and red filters together. You will probably see a deep yellow. Can you explain this result? (8)

LABORATORY ACTIVITY 28: INDEX OF REFRACTION

INTRODUCTION:

When light passes from one medium to another it bends. This process is called the refraction of light. The degree of refraction, or amount the light bends, depends upon the two media involved.

For each medium there is a number, called the index of refraction, which describes the relationship between the angle of incidence and the angle of refraction when light enters that medium from a vacuum. In practice, measurements are normally made on light moving from air into a second medium, because the use of air instead of a vacuum has very little effect on the results.

Refraction is an important aspect of the behavior of light, for in order to understand the path that light follows as it passes through the different media within the eye, it is necessary to have a knowledge of the indices of refraction that are involved.

In this activity you will determine the index of refraction of water and of glycerin by making measurements of the angle of incidence and the angle of refraction for each medium.

$$\text{Index of refraction} = n = \frac{\sin \alpha}{\sin \beta}$$

where α is the angle of incidence and β is the angle of refraction.

MATERIALS:

- glycerin
- semicircular transparent container
- 4 paper clips
- 2 straight pins
- 3 sheets graph paper
- soft cardboard ($8\frac{1}{2}$" x 11")
- mm ruler
- beaker, 150-ml
- glass-marking pencil

PROCEDURE:

1. Fasten a sheet of graph paper to a piece of cardboard with the paper clips. Draw heavy lines that divide the graph paper into four equal parts. Label the top half "AIR" and the bottom half "WATER," as shown in Figure 1.

2. Use a ruler to locate a point halfway along one long edge of the flat side of the container (Figure 2). With a glass-marking pencil, draw a vertical line through the point.

3. Fill the container about $\frac{3}{4}$ full with tap water. Be careful not to wet the outside of the container.

4. Place the container on the graph paper with the vertical line on the flat side directly above the intersection of the two heavy lines on the graph paper, as shown in Figure 3.

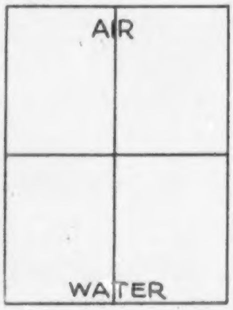


FIGURE 1

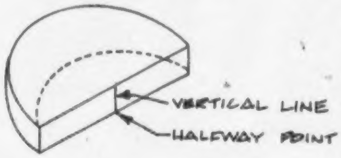

VERTICAL LINE
HALFWAY POINT

FIGURE 2

5. Draw a line around the round part of the container with a pencil, as shown in Figure 3.

6. Place a pin vertically in the upper-right quadrant of the graph paper, to the right of an imaginary diagonal, to the left of an imaginary vertical line from the corner of the container, and at least 2 cm from the flat side of the container, as shown in Figure 4.

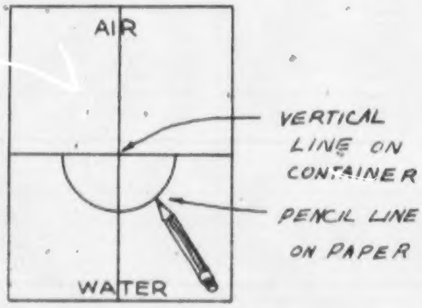

AIR
WATER
VERTICAL LINE ON CONTAINER
PENCIL LINE ON PAPER

FIGURE 3

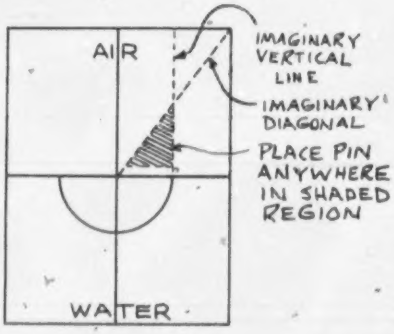

AIR
WATER
IMAGINARY VERTICAL LINE
IMAGINARY DIAGONAL
PLACE PIN ANYWHERE IN SHADED REGION

FIGURE 4

7. Look through the water in the rounded portion of the container. With one eye, try to line up the vertical line and the pin so that the vertical line hides the pin (Figure 5). Figure 6 shows what you should see.

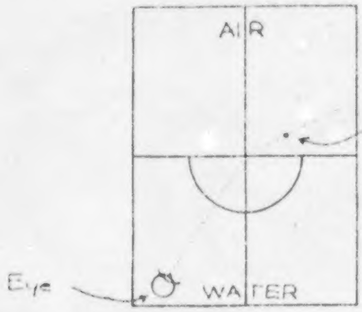


FIGURE 5

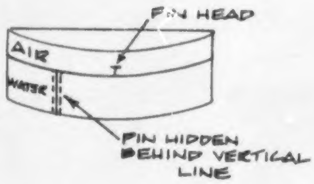


FIGURE 6

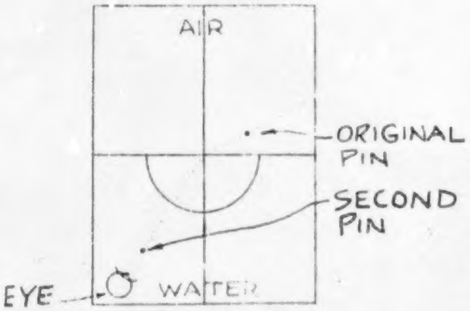


FIGURE 7

8. Without moving your eye, place a second pin vertically between your eye and the container (Figure 7). Put this pin in a position that appears to be on the same line as the vertical line and the other pin when you look through the container. This pin should appear to stand directly in front of the vertical line.

9. Remove the container. Draw lines and label angles as shown in Figure 8.

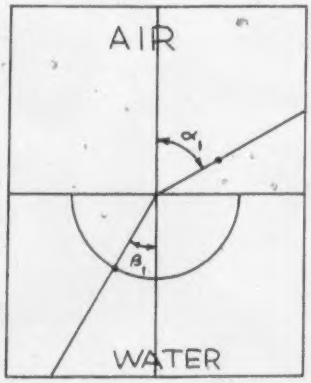


FIGURE 8

10. On the same sheet of graph paper, repeat Steps 4 through 9 three more times for water. Use a different pin position for each repetition, but be sure each position is within the shaded region shown in Figure 4. Use a different subscript to label each pair of angles so you can tell which angles go together.

11. Empty the container and dry it.

12. Repeat Steps 1 through 10, using a new sheet of graph paper and putting glycerin instead of water in the container.

13. Empty the container, wash it out and dry it thoroughly. Repeat Steps 1 through 10 with a third sheet of graph paper for air/air (with the container empty).

14. When you have completed the three graphs, sign your name and hand the graphs in to your instructor. They will be returned to you in Mathematics class. The calculations for this activity will be done there.

DISCUSSION QUESTIONS:

1. With which substance in the container--water, glycerin or air--is there the greatest difference between α and β for a given α? Explain.

2. Which substance in the container causes light to bend the most?

3. Why does light bend as it passes through water and glycerin?

LABORATORY ACTIVITY 29: MAKING LENSES

INTRODUCTION:

In this activity you will be constructing two lenses (Part I) and making two sucrose solutions (Part II) to fill these lenses with. The lenses will be two different sizes and the solutions will be two different concentrations of sucrose. Using these materials, you can vary two factors that affect the focal length of a lens: its shape and its index of refraction. In the next activity you will determine the focal lengths using the lenses and solutions that you prepare today.

PART I: MAKING LENSES

MATERIALS:

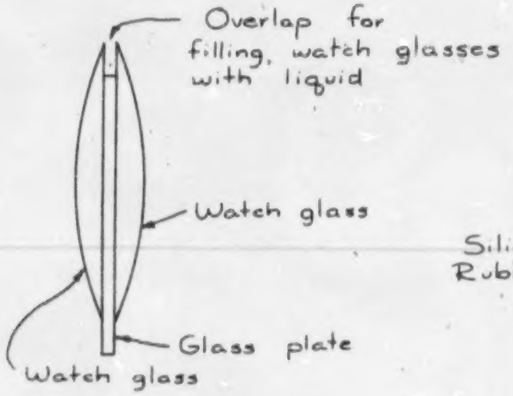
2 watch glasses, 100-mm diameter
2 watch glasses, 50-mm diameter
glass plate, 100 mm x 110 mm
glass plate, 50 mm x 60 mm
tube of air-curing silicone rubber
glass-marking pencil

PROCEDURE:

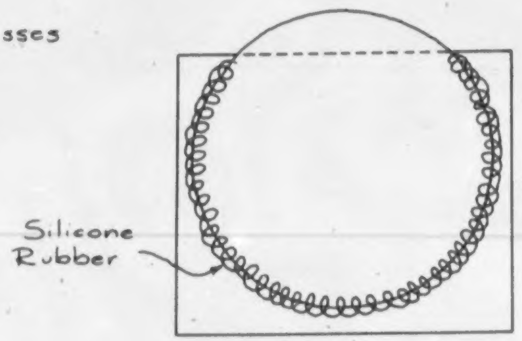
1. In this part of the activity one member of the team can make a large lens and one a small lens. The procedure is the same for both.

2. Carefully wash and dry the glass plate and the two watch glasses.

3. Lay the glass plate on the table. Set a watch glass on the plate with the watch glass overlapping the glass plate by about 1 cm. The overlap should be enough for filling the watch glass with liquid from a pipet or squeeze bottle. (See diagram below.) With a marking pencil, outline the watch glass on the plate.



EDGE VIEW



FRONT VIEW

4. Turn the plate over and outline the watch glass on the other side, making sure the two outlines line up.

5. Place a layer of silicone rubber sealant about .5 cm wide just inside the outline on one side of the plate. Wipe any fingerprints off the watch glass and set the watch glass onto the ring of rubber sealant, using the outline as a guide. Wait 1 to 2 minutes. Then place a layer of sealant around the edge of the watch glass. This will seal any leak between the watch glass and glass plate.

6. Record the time. Allow 10 minutes for the sealant to dry. While you are waiting, you can get started on Part II.

7. When the 10 minutes are up, wipe off fingerprints from the other watch glass and cement it onto the other side of the plate. Make sure the two watch glasses line up with each other.

8. Set the lens aside for one day for the rubber to cure. Proceed to Part II.

9. After the rubber sealant has cured for one day, check for leaks as follows. Fill each side of the lens with water, dry the outside, and look for leaking. If a leak is present, note its location with a glass-marking pencil. Empty the lens, dry the outside thoroughly and place a layer of rubber on the defective area.

10. Set the lens aside for one day to let the new layer of rubber cure.

If you found a leak and repaired it in Step 9, repeat Step 9 again a day after the repair, to check for further leaks. Repair any leaks.

PART II: PREPARING SUCROSE SOLUTIONS

MATERIALS:

2 beakers, 250-ml	balance
2 Erlenmeyer flasks, 250-ml	stirring rod
graduated cylinder, 100-ml	2 cork stoppers, #14
graduated cylinder, 10-ml	sucrose

PROCEDURE:

1. In Laboratory Activity 30 you will be filling your lens with two different sucrose solutions. The two solutions needed should have the following concentrations.

$$\frac{50\text{ g sucrose}}{200\text{ g solution}} \quad \text{and} \quad \frac{100\text{ g sucrose}}{200\text{ g solution}}$$

2. The mass of water in each solution may be found by subtracting the mass of the sucrose from the mass of the solution. The first solution will contain 50 g sucrose + 150 g H_2O. The second solution will contain 100 g sucrose + 100 g H_2O.

Since 1 g of H_2O has a volume of 1 ml, the two solutions will consist of 50 g sucrose + 150 ml H_2O and 100 g sucrose + 100 ml H_2O.

3. Label your two beakers "A" and "B." Determine and record the mass of each beaker to ± 0.1 g.

4. Use beaker B to weigh out 50 ± 0.1 g sucrose.

5. Sucrose dissolves best in hot water. Add 150 ± 2 ml of hot tap water to beaker A.

6. Add the sucrose to the water slowly, while stirring, until all the sucrose is dissolved.

7. Pour the solution into an Erlenmeyer flask. Label the flask "50 g/200 g."

8. Rinse and dry beaker A.

9. Repeat Steps 4 through 7, but use 100 ± 0.2 g sucrose and 100 ± 2 ml of hot tap water. Label the second flask "100 g/200 g."

10. Initial both flasks, and stopper and store them.

LABORATORY ACTIVITY 30: DETERMINING THE FOCAL LENGTH OF LENSES

INTRODUCTION:

In this activity you will use the lenses you constructed during the last activity to collect data from which you can determine the focal lengths of the lenses.

In Part I you will measure the dimensions of your lens. You will use these measurements later in the Mathematics class to calculate the focal length of the lens, using formulas.

In Part II you will work with images that the lens produces, using a light source and a screen. You will vary the index of refraction of the lens by filling it with three different liquids: water and the two sucrose solutions you prepared during the preceding activity. You will measure the distances involved and use these measurements in the Mathematics class to make a second calculation of the focal length of the lens.

By comparing the results from Part I with the results from Part II, you will be able to determine how closely the focal length calculated from the dimensions of the lens agrees with the focal length calculated from the distances of the images the lens produces.

MATERIALS:

- small and large lenses made in Laboratory Activity 29
- two sucrose solutions made in Laboratory Activity 29
- meter stick
- mm ruler
- 3 index cards (4" x 6" or 5" x 8")
- masking tape
- pipet, 10-ml
- wash bottle
- scissors
- light source:
  - 100-watt clear bulb
  - bulb socket with cord and plug
  - ring stand with clamp
- Data Sheet 30

PROCEDURE:

PART I: DETERMINING THE THEORETICAL FOCAL LENGTH

1. Consider the depth, d, of the watch glass to be half of the thickness of the lens. Measure this distance to the neareast 0.1 cm as shown in Figure 1. Be sure the glass plate is parallel to the table top.

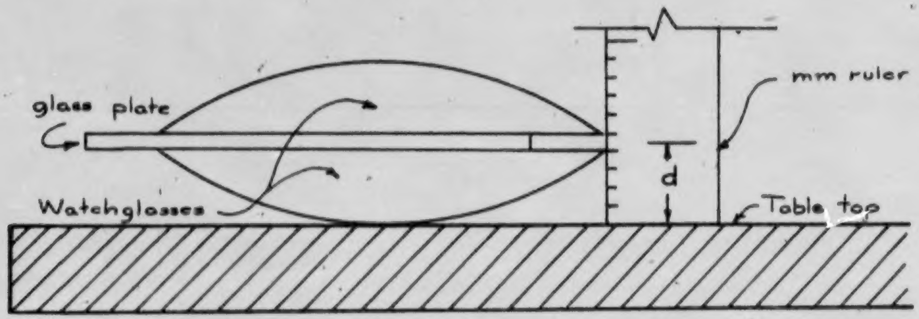


FIGURE 1: Measuring the depth, d.

2. Record "d" on the data sheet.

3. Measure and record the width, w, of the watch glass to the nearest 0.1 cm as shown opposite.

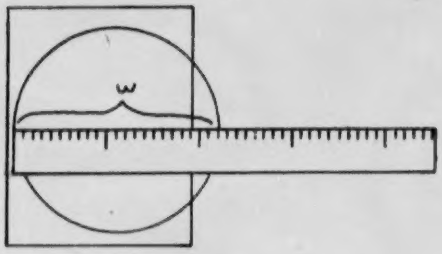


FIGURE 2: Measuring the width, w.

PART II: DETERMINING THE EXPERIMENTAL FOCAL LENGTH

1. Tape the meter stick to the table top.

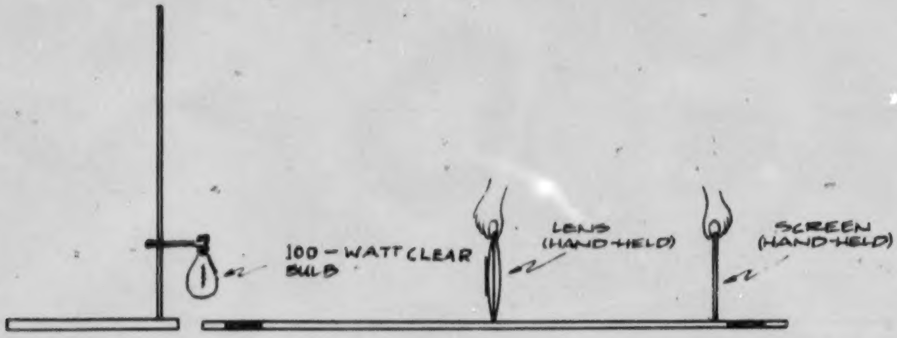
2. Support the light source with the ring stand and clamp.

3. Position the bulb so that the filament is parallel to the lens and directly above the end (zero-point) of the meter stick (Figure 3). Look at the wires that support the filament. The bulb should also be positioned so that no support wire is between the filament and the lens. This will prevent the support wire from being in the path of the light that leaves the bulb.

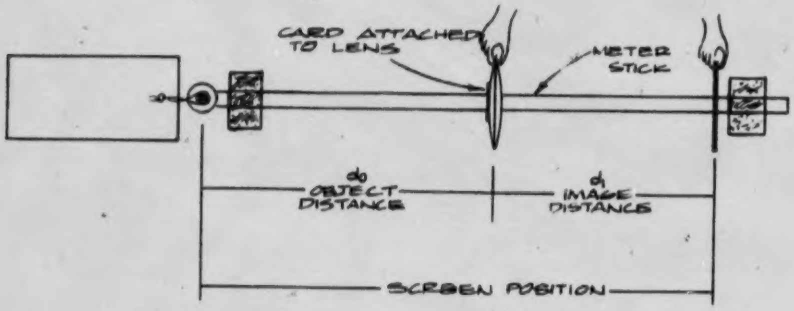
4. Cut two index cards so that each is about 7.5 x 7.5 cm. Cut a round hole about 2.5 cm in diameter in the center of each. (You can use a quarter as a template for drawing the hole.) Tape a card to each lens so that the center of the hole in the card coincides with the center of the lens. Do not put tape over the hole in the card.

5. Use a wash bottle to fill the small lens (both sides) with water.

6. One student should hold the small lens vertically on the meter stick at the 30-cm mark. Make sure the side with the card attached is toward the light source. Align the center of the lens with the filament of the bulb. Turn on the light.


100-WATT CLEAR BULB
LENS (HAND-HELD)
SCREEN (HAND-HELD)

SIDE VIEW


CARD ATTACHED TO LENS
METER STICK
d_o OBJECT DISTANCE
d_i IMAGE DISTANCE
SCREEN POSITION

TOP VIEW

FIGURE 3: Set-up for determining focal length.

Another student should use an index card for a screen and move the screen back and forth along the meter stick (on the far side of the lens) until an image of the bulb filament comes into focus. Remember to keep the center of the lens aligned with the bulb. Note: the image may not be too sharp. Obtain the best focus you can.

When the focus is obtained, record on the data sheet the screen position in cm (the distance from the zero-point of the meter stick to the position of the screen). Also record the object distance in cm for the small lens (Figure 3).

7. Repeat Step 6 with the small lens at 50 cm.

8. Repeat Step 6 with the small lens at 70 cm.

9. Pour the water out of the small lens, rinse once with 50g/200g sucrose solution (using the pipet), and refill with the 50g/200g solution (using the wash bottle).

10. Repeat Steps 6 through 8 (lens at 30 cm, 50 cm and 70 cm).

11. Pour out the 50g/200g solution, rinse once with 100g/200g sucrose solution, and refill with the 100g/200g solution.

12. Repeat Steps 6 through 8 using the 100g/200g solution.

13. Extend the range of measurement by adding the centimeter rule to the end of the meter stick. This will be needed for the large lens.

14. Reverse roles with your partner and repeat Steps 5 through 12 using the large lens. In order to keep the center of the large lens aligned with the filament of the bulb, you may have to raise the bulb.

15. Subtract d_o from the screen position to obtain d_i for each trial. Record.

16. Put your name on your data sheet and hand it in. It will be returned in Mathematics class.

DISCUSSION QUESTION:

Were you able to get a sharp image at the focus? If not, speculate as to why.

LABORATORY ACTIVITY 31: DISSECTION OF THE EYE

INTRODUCTION:

Vision is perhaps the most important sense by which humans gain knowledge of the external environment. The receptor organ that makes vision possible is the eye. Light rays pass into it and trigger nerve impulses that travel to the brain, where they are converted to visual images.

One of the methods commonly used to study the structure and function of an organ is dissection. You have used this method previously to study the lung, the digestive tract and the heart. In this activity you will once again make use of this technique to study the structure of the eye. In this activity, you will be using a sheep's eye; its structure is very similar to that of the human eye and thus will provide information relevant to the human eye.

MATERIALS:

sheep eye
Petri dish (or dissecting tray)
razor blade
dissecting scissors, or scissors with sharp points
forceps
hand lens
hand mirror
light source (to be shared by all students)

PROCEDURE:

1. Examine the eye and locate the optic nerve. It is the whitish stump sticking out of the back of the eyeball. This is where all the nerve fibers from the retina join together. You will also see a series of muscles around the eye. What do you think the function of these muscles is? (1)

2. The optic nerve is surrounded by whitish fatty tissue. Remove this with the help of the forceps or a pair of scissors and examine the optic nerve. Where does the optic nerve enter the eyeball? (2)

3. Examine the outer covering of the eyeball. Can you locate the sclera? (3) The cornea? (4) How does the cornea differ in appearance from the sclera? (5)

4. Put the eye on a wet paper towel in the Petri dish so that the cornea is up. Holding the eye firmly (don't squeeze it) make a small incision (about 3 mm deep) in the cornea near the edge. A watery substance will begin to ooze out through the cut. What is this substance and what is its function? (6)

5. Insert your scissors into the cut you just made, and cut all the way around the cornea. Remove the cornea with a pair of forceps. Make a drawing of the eye with the cornea removed, labeling sclera, iris, pupil and lens. (7)

6. Use the hand lens to look through the pupil and examine the lens of the eye. It is transparent in the living eye but will appear cloudy or opaque in a preserved specimen. Make a note of your observations. (8)

7. You can easily pop the lens out of the eye by squeezing the eye gently. Remove the lens and describe it--the shape, color, texture, etc. (9)

8. Behind the lens lies the vitreous humor. Take the eye over to the lamp that has been set up and, using a hand mirror, look inside the eye. If necessary, remove any tissue that prevents you from seeing the back of the eye. Record your observations. (10)

9. Squeeze the vitreous humor out of the eye into a wet paper towel. Do you see a dark ring-shaped muscular area around the space where the lens was? (11) This is the ciliary body and contains the ciliary muscles, which change the shape of the lens.

10. Beginning at the edge of the cut in the front of the eye, make a cut back to the optic nerve on either side. (Don't touch the inside of the eye with your fingers as you do this.)

11. Turn the eye inside out and look for a thin gray or blackish-blue membrane. This is the retina. In the retina are located the specialized cells that are sensitive to light.

12. Using a razor blade, scrape the inside surface of the eye until you reach the sclera. What layers do you pass through? (12)

LABORATORY ACTIVITY 34: TESTING VISUAL ACUITY

INTRODUCTION:

In this activity you will administer the Snellen test to one another. Make sure that each member of your group has an opportunity to administer the test. It is important that each of you be familiar with the test materials when you test primary-school children later.

The procedure for administering the Snellen test is described below. However, before proceeding with the testing, you should first get together with all the members of your group, read the informational material that follows and make any necessary preparations. For example, your group will need to mark off the testing area you will be using and check the illumination in the room, etc., before beginning the actual testing. Also, we suggest that you come to a decision as to what method you will use to explain the procedure to the children you will be testing, and then practice this method on the other members of your group. If you follow this procedure you will know exactly what to do and how to do it when you administer the test to the elementary-school students.

Before proceeding, check the size of the room and the room lighting as follows.

1. The room should be large enough so that there is a length of at least 25 feet of clear floor space with even, glare-free lighting over the entire length.

2. Visual acuity increases as the intensity of light increases until a level is reached that causes eye discomfort, and visual acuity decreases as the intensity of light decreases. It is therefore important to have the entire area over which the testing is to be done properly lighted at all times. The intensity of light over this area should be 10 to 15 foot-candles and evenly diffused. The intensity should be checked with a light meter that reads in foot-candles, if one is available.

In performing the Snellen test, consider the following guidelines taken from A Guide for Vision Screening in California Public Schools, Calif. State Dept. of Education, Sacramento, 1964, p.8.

ADMINISTERING THE SNELLEN TEST:

In order to secure the confidence, understanding, and cooperation of pupils when they are taking the test for the first time, explain to them the purpose and procedures. With very young children who have never taken a vision test, demonstrate the procedure with the large symbol E card. Turn the E to various positions and, as it is held in each position, show the pupil how to indicate the direction in which the legs of the E point. This procedure may be carried on in the spirit of a game; the pupils indicate with both arms the direction in which the "legs" of the "table" are pointing. The pretesting activities may be carried out in regular classrooms.

Pupils who are far enough along in school that they can be relied upon to report verbally the direction in which the symbol points may be taught to respond by saying "left," "right," "up," or "down." However, they may be permitted to indicate the positions by pointing.

Testing. In testing a pupil, employ the following practices:

Adopt and employ a standard testing procedure.

If the pupil is wearing glasses, test him without glasses and indicate on the test form that he had glasses.

Test the vision in one eye at a time--the right eye first, the left eye next. Use an occluder or hold a small cover card obliquely along the nose of the pupil to cover the eye not being tested. Pupils are to keep both eyes open during the test--the one being tested and the one covered by the card. Care should be taken that the card does not press on the eye.

Use a fresh cover card with each pupil so as to prevent any infectious condition from being communicated from one pupil to another.

Do not allow the pupil to squint.

MATERIALS:

set of Snellen cards (hand-held "E" set)
3" x 5" index cards
Visual Acuity Test Form
yardstick (or tape measure)
light meter (optional)

PROCEDURE:

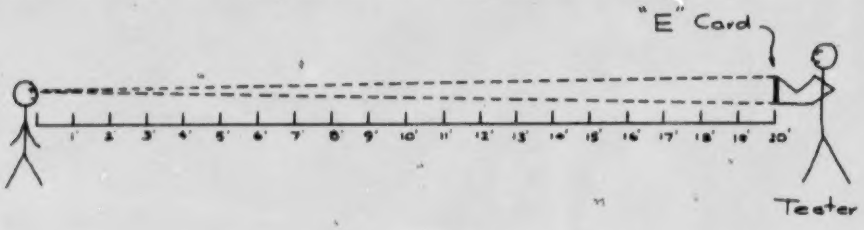
1. Measure a distance of 20 feet (or 6.1 meters). Make chalk lines on the floor at both ends of one 20-foot distance. Record the distance.

The location of the subject should be protected from bright or glaring light coming from directly in front of him.

2. Seat or stand the subject at one end of the measured 20 feet.

3. Exhibit various sizes of "E's" from the hand-hold set, starting with the 50 card. Hold each card directly over the chalk line 20 feet from the subject. Determine the smallest-sized E that the subject can accurately indicate the direction of at 20 feet.

The visual acuity testing situation should look like the following diagram.



4. At this point the tester should flip the E card in three or four different directions to determine whether the subject can accurately tell the correct direction on every trial.

5. Record the number of the card on your test form under the title, "Standard Distance."

6. Record the visual-acuity ratio (distance between subject and "E" card/standard distance) and the scale on your test form. Use the table to the right to determine the appropriate scale for the visual-acuity ratio.

Acuity Ratio	Scale
20/5	1
20/7.5	2
20/10	3
20/15	4
20/20	5
20/25	6
20/40	7
20/50	8
20/100	9
Less than 20/100	10

LABORATORY ACTIVITY 36: TWO-POINT TOUCH THRESHOLDS

INTRODUCTION:

Touch is detected by specialized nerve endings (receptors) that are located in the skin and just beneath the skin. However, touch receptors are not evenly distributed in all parts of the skin. Some areas contain many more touch receptors than other areas. The skin is most sensitive to touch in areas where there is a high concentration of touch receptors, that is, where the touch receptors are closest together.

If the skin is touched simultaneously by two objects that are close enough together, the two touches are perceived as one touch. It is thought that they can be perceived as two touches only if they stimulate at least two different touch receptors. On a given part of the body, the minimum distance between two simultaneous touches that can be perceived as two touches is called the "two-point touch threshold" for that part of the body. Theoretically, this distance is equal to the average distance between touch receptors on that part of the body.

In this activity, you will estimate the two-point thresholds for four areas of your body: the palm, the back of the hand, the lower back and the lips. Your results should provide an indication of the relative concentrations of touch receptors in each of the areas tested.

MATERIALS:

plastic drinking straw
small cork to fit end of straw
8 map pins
metric ruler
blindfold

PROCEDURE:

PART I: MAKING THE PROBE

Note: a team of three people is needed to perform the two-point touch threshold tests; one probe is sufficient for each team.

1. Insert a small cork into the end of a plastic drinking straw.

2. Insert four map pins at right angles as shown in Figure 1A. Each of these four pins should be 2 mm from the corked end of the straw. The pins should go through the straw and into the cork.

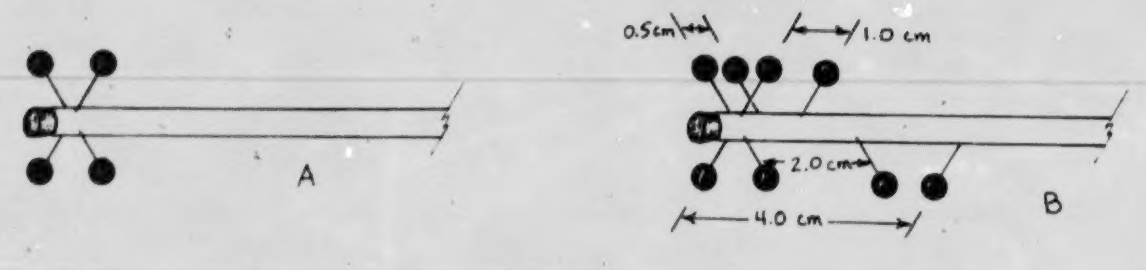


FIGURE 1: Making the probe.

3. Insert a pin at a point 0.5 cm from one of the pins already in place, and in line with it, as shown in Figure 1B.

4. Rotate the straw 90° and insert a pin at a point 1.0 cm from the pin at the end.

5. Rotate the straw 90° and insert a pin at a point 2.0 cm from the pin at the end.

6. Rotate the straw 90° and insert a pin at a point 4.0 cm from the pin at the end.

7. You should now have four pairs of pins in place that are 0.5, 1.0, 2.0 and 4.0 cm apart, respectively. The completed probe should appear as shown in Figure 1B.

PART II: PERFORMING THE TEST

1. The test requires a team of three students: a subject, a tester and a recorder. Rotate the roles as you perform the activity, until each of you has acted in each of the three roles.

2. In using the probe, it is important that both pin heads touch the skin at the same time and with the same pressure. Hold the straw in the middle and practice touching the pairs of pin heads to the back of your own hand. The touch should be fairly firm and should last approximately one second. The pins that are farther apart are more difficult to apply simultaneously. Practice touching each of the four pairs of pin heads to your skin.

3. Before starting the test, position the subject so that his hand and arm are comfortable when held still. At this time, the subject should be blindfolded so that he cannot observe what the tester is doing.

4. The recorder should prepare a data table similar to the one shown below.

		DISTANCE BETWEEN PIN HEADS (cm)											
		CONTROL (0 cm)				.5		1		2		4	
SITE	PALM												
	BACK OF HAND												
	BACK												
	LIPS												

5. To begin the test, the tester touches the pin heads to the area of the subject's palm indicated by the shading in Figure 2A on the following page. The subject must decide whether he feels one pin head or two. The tester should not repeat a trial even if the subject asks for a repeat. As a check, the tester must occasionally touch only one pin head to the skin. Each of the four pairs of pin heads should be applied to the skin in mixed-up order until all of the spaces on the data sheet for the palm have been filled with the subject's responses. For each site there should be 12 responses in all.

Scoring is done as follows. Suppose the subject's palm is touched with the pin heads 1.0 cm apart. If the subject says that he feels two pin heads, the recorder should put a "+" on the data sheet in the appropriate space. If the subject says that he feels one pin head, a "-" should be entered on the data sheet. If the subject is unsure, ask for his best impression, even if he feels he is just guessing.

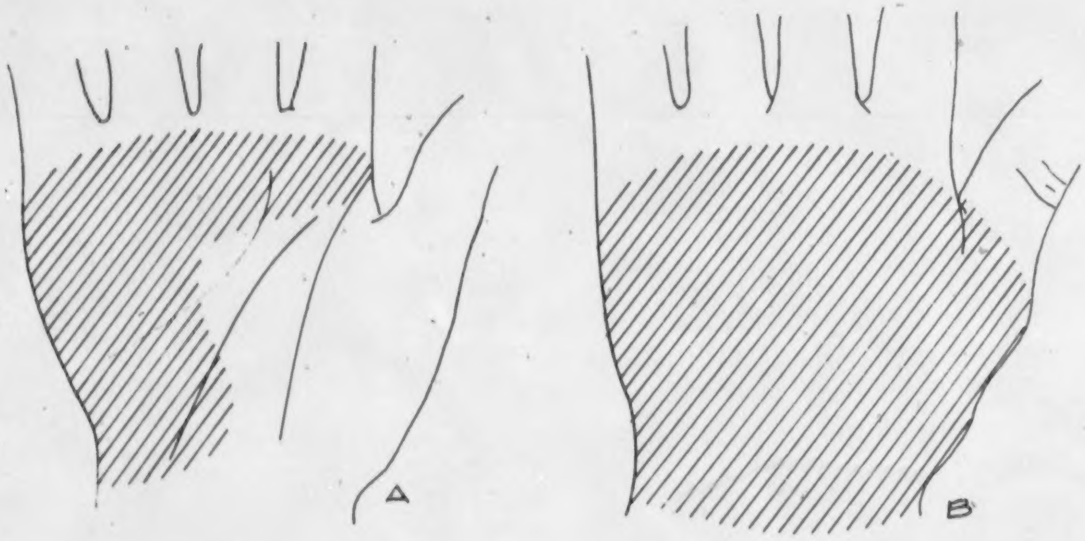


FIGURE 2: The areas for pin-head placement on (A) the palm and (B) the back of the hand.

6. When the test on the palm is completed, repeat the test on the back of the hand. The area to be used is shaded in Figure 2B. Do not tell the subject how he has done until the tests on all four sites are completed.

7. Repeat the test on the skin of the lower back (shaded area in Figure 3).

8. Repeat the test on the skin of the lips. (Note: for the test of the lips, it is not necessary to use the pin heads that are 4 cm apart. This pair of pins is virtually impossible to apply correctly to the lips. For the purposes of this test, it may be assumed without testing that the subject answers correctly when the pin heads, gapped at 4 cm, are applied to the lips.)

9. Exchange the roles of tester, subject and recorder, and repeat the test until all members of your team have taken the test.

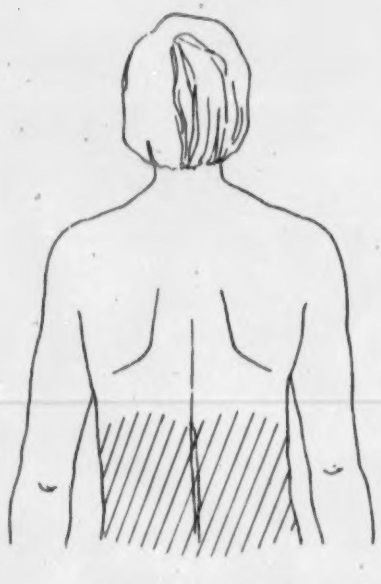


FIGURE 3: The area for pin-head placement on the lower back.

DISCUSSION QUESTIONS:

1. Which of the four areas seem to be the most sensitive to two-point touching? Rank the four areas on the basis of their sensitivity. (Ignore the responses in the "control" columns.)

2. What would you estimate your two-point thresholds to be (in centimeters) from the results of your test? Can you detect significant differences between your thresholds and your classmates'?

3. Check the results of other teams and compare females with males for sensitivity.

4. Why might it be advantageous to have greater sensitivity to touch in some areas than in others?

5. The areas tested were chosen in part for their relative lack of hair. Why?

LABORATORY ACTIVITY 37: TASTE THRESHOLDS

INTRODUCTION:

In this activity you will measure your taste thresholds for salt, sugar (sucrose) and saccharin. As you might expect, your taste threshold for a given substance is the lowest concentration of that substance that you can taste. Therefore, to measure your taste threshold for salt you taste a number of salt solutions of different concentrations and decide at which concentration you first perceive the taste of salt.

It is important during this activity that you not know what concentration you are tasting. Prior knowledge could easily affect the results. (Recall the placebo effect.) For this reason you will administer the test to each other. The subject should not know what solution the tester is administering on any given trial.

MATERIALS:

.032 M NaCl solution
.032 M sucrose solution
64×10^{-6} M saccharin solution
6 medicine droppers
paper cups
blindfold

PROCEDURE:

Note: three people are needed to perform the taste-threshold test. While one member of your team is preparing the sucrose dilutions, the other two members can be preparing dilutions of NaCl and saccharin (see Steps 15 and 16), if enough paper cups are available.

1. Label 5 cups as follows: .032 M, .016 M, .008 M, .004 M and .002 M.

2. In an unmarked cup, obtain approximately 100 ml of .032 M sucrose solution. Label this vessel "measuring cup."

3. Pour approximately one half of the sucrose solution from the measuring cup into the cup marked .032 M.

4. On the measuring cup mark a line indicating the level of the remaining solution. This cup is used in the following steps for preparing the remaining dilutions. Each dilution is prepared by diluting the previous solution by a factor of two.

5. Pour the contents of the measuring cup into the cup marked .016 M.

6. Fill the measuring cup to the mark with water. Pour the water into the cup marked .016 M. Swirl the cup to mix the contents thoroughly.

7. Fill the measuring cup to the mark with .016 M sucrose.

8. Repeat Steps 5, 6 and 7 using the cup marked .008 M. Continue making dilutions until you have filled all of the labeled cups with the proper solutions.

9. Rinse the measuring cup thoroughly and fill it with fresh water. Place a clean medicine dropper in each of the six cups.

10. Organize your team into a subject, tester and recorder. The recorder should prepare a data sheet similar to the one shown below.

CONCENTRATION

SOLUTION	0.0M (control--water)					.002 M		.004 M		.008 M		.016 M		.032 M	
SUCROSE															
NaCl															
SACCHARIN	0.0M (water)					$4 \cdot 10^{-6}$M		$8 \cdot 10^{-6}$M		$16 \cdot 10^{-6}$M		$32 \cdot 10^{-6}$M		$64 \cdot 10^{-6}$M	

11. Blindfold the person who has been chosen as the subject. The subject should rinse his mouth thoroughly with water.

12. To perform the test, the tester applies three drops of each solution in mixed-up order to the tongue of the subject. The subject must decide whether he does or does not taste the sucrose. The recorder should record the subject's responses in the data sheet. A plus (+) should be marked for a correct response and a minus (-) for an incorrect response. Between each application, the subject should rinse his mouth briefly with a small quantity of water. Testing should continue until the entire row on the data sheet is completed (15 responses in all). Under no circumstances should a test be repeated, or should more than three drops be applied to the tongue.

13. Interchange the roles of tester, subject and recorder and repeat Steps 11 and 12 until all members of your team have taken the test.

14. Rinse the cups and the droppers thoroughly with water.

15. Repeat Steps 1 to 14 using the .032 M NaCl solution. The NaCl dilutions should be prepared in the same manner as the sucrose dilutions.

16. Repeat Steps 1 to 13 using the 64 x 10^{-6} M saccharin solution. The saccharin dilutions are prepared in the same manner as the sucrose and NaCl dilutions

except that the cups should be relabeled as follows: 64×10^{-6} M, 32×10^{-6} M, 16×10^{-6} M, 8×10^{-6} M and 4×10^{-6} M.

DISCUSSION QUESTIONS:

1. What observations can you make about people's sensitivity to the tastes of salt, sucrose and saccharin from the results of this activity?

2. Calculate the molecular mass of salt (NaCl) and sucrose ($C_{12}H_{22}O_{11}$). Why did this activity compare solutions of equal molarity rather than solutions containing equal masses of salt and sugar?

3. Do the results you obtained agree with the manufacturer's claim that, "Saccharin is 300 to 500 times as sweet as sugar"?

4. How do your results compare with the value given for quinine in Section 37-1 of the Student Text?

5. How could this activity be converted into a "double-blind" test?

6. What mass of solute is needed to prepare 1000 ml of a .032 M sucrose solution? 100 ml of a .032 M NaCl solution? 100 ml of a 64×10^{-6} M saccharin solution? (The molecular formula of saccharin is $C_7H_5NO_3S$.)

LABORATORY ACTIVITY A:

VOLTAGE SOURCES AND ELECTRIC CIRCUITS

INTRODUCTION:

In order for current to flow through a wire, the potential energy of the electrons at one end must be greater than at the other end. In other words, there must be a source of voltage, such as a battery or a wall outlet. Although voltage may be produced in a variety of ways, all voltage sources function by using energy in some form to produce a flow of electrons.

In this activity, you will use several voltage sources with light bulbs in various combinations to investigate some of the properties of electric circuits. First, you will use flashlight batteries (often called "dry cells") to make a simple circuit with a light bulb. Then, you will make a simple battery (a "wet cell") by immersing two dissimilar electrodes in an ionic solution. Finally, you will use the BIP to provide voltage for some simple circuits.

PART I: A SIMPLE CIRCUIT

MATERIALS:

2 batteries
connecting wire
wire cutter-strippers
light bulb

PROCEDURE:

1. Examine a flashlight battery. Note that it has a center post at one end which serves as the positive terminal, and a flat base at the other end which serves as the negative terminal. These terminals are charged as a result of chemical reactions inside the battery. Examine the label on the battery and record its voltage.

2. Examine the light bulb. The thin wire inside the bulb is called the filament (see Figure 1). The light bulb glows only when electrons are flowing through the filament. The first problem in this part of the activity is to devise a method for making the light bulb glow using a battery and some wire. Make a simple drawing and a brief explanation of the circuit you devise. Indicate the areas on the light bulb to which the wires must be connected. (1)

3. Devise a method for making the bulb glow more brightly, using an additional battery. Make a drawing of your circuit. (2) Why does the bulb glow more brightly in this circuit? (3) How does the arrangement of the batteries affect the results? (4)

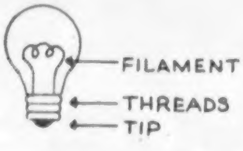


FIGURE 1: **A light bulb.**

PART II: MAKING A WET CELL

MATERIALS:

beaker, 50-ml
graduated cylinder, 100-ml
zinc electrode
carbon electrode
light bulb
light-bulb holder

potassium dichromate, 0.2 M
sulfuric acid, 1.0 M
2 connecting wires with alligator clips
wire cutter-strippers
screwdriver

PROCEDURE:

1. To make a wet cell, first mix approximately 20 ml of 1.0 M sulfuric acid and 20 ml of 0.2 M potassium dichromate in a 50-ml beaker. The reactions that take place between this ionic solution and the carbon and zinc electrodes provide the energy needed to produce a voltage and a flow of current.

2. Screw the light bulb into the light-bulb holder. The threads and the tip of the light bulb touch contacts inside the holder, which in turn are connected to the two screws on the outside.

3. Attach the bare ends of the two alligator-clip connecting wires to the screw connections on the light-bulb holder as shown in Figure 2. The wire should be wound clockwise around the screw, so that a good connection is made as the screw is tightened.

4. Attach one of the alligator clips to the carbon electrode, and place the electrode in the ionic solution.

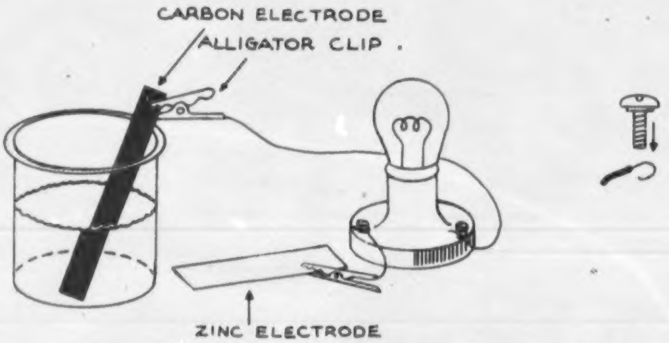


FIGURE 2: A. Making a simple wet cell. B. How to attach a wire to the screw connection on the light-bulb holder.

5. Attach the other alligator clip to the zinc strip. Then dip the zinc electrode into the beaker, being careful to avoid touching the carbon electrode. If all of the connections have been made properly, the light should go on. Examine the two electrodes carefully and record any observations. (5) (Important: The zinc electrode deteriorates rapidly if left in the acidic solution. Therefore, make your observations as quickly as possible, and remove the zinc electrode whenever you are not observing the cell directly. The electrode should be rinsed thoroughly with water after it has been removed from the acidic solution.)

6. Does the wet cell light the bulb as brightly as the dry cell? (6) How do you think the intensity of the light is related to the voltage provided by the cells? (7) How does the voltage of the wet cell compare with the voltage of the dry cell? (8)

PART III: USING THE BIP AS A VOLTAGE SOURCE

MATERIALS:

- BIP
- connecting wire
- wire cutter-strippers
- screwdriver
- 2 light bulbs
- 2 light-bulb holders

PROCEDURE:

1. To use the BIP as a voltage source, first disconnect the wires with alligator clips from the light-bulb holder. Attach two lengths (about 30 cm) of connecting wire to the screws. Connect the free ends of the wires to pins S and X on the programming panel of the BIP as shown in Figure 3. (Note: Do not plug in the BIP until Step 3.)

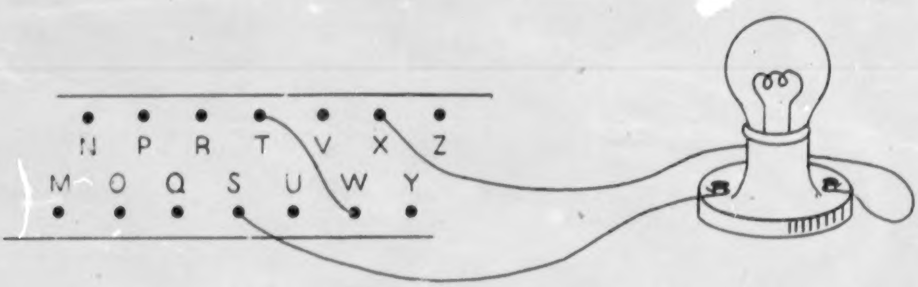


FIGURE 3: Using the BIP as a voltage source.

2. Connect pin T to pin W on the programming panel of the BIP.

3. Plug in the BIP. The light should go on. If it doesn't, recheck your connections carefully until you locate the problem. (It is possible for a light bulb to burn out.) How does the intensity of the light compare with the results obtained using a battery? (9) What do these results suggest about the amount of voltage supplied by the BIP? (10) Do you think that the BIP is necessarily a "better" voltage source than flashlight batteries? (11) What advantages and/or disadvantages does the BIP have? (12)

4. Disconnect one of the wires at either pin S or pin X. Then connect another light bulb to the circuit as shown in Figure 4. When the proper connections have been made, two light bulbs should be lit. This type of arrangement is called a series circuit, which means that current first passes through one light and then through the other. The current follows a single path from the voltage source (i.e., the BIP) to the first light, to the second light, and back to the voltage source. (This is in contrast to the kind of circuit in Step 6.) Do the lights in this circuit glow as brightly as when only one light is being used? (13) How can this be explained with your knowledge of voltage and energy? (14)

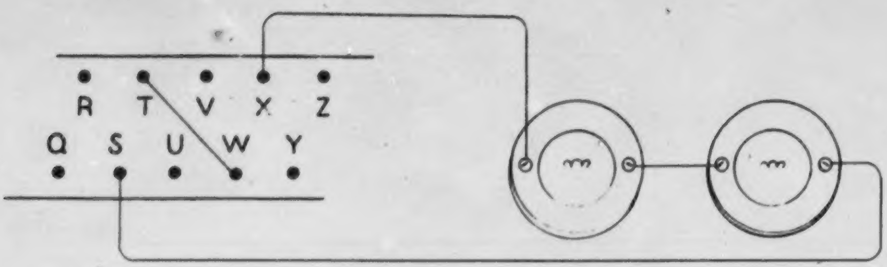


FIGURE 4: A series circuit.

5. Unscrew one of the lights from its holder. What happens to the other light? (15) How can this be explained? (16)

6. Assemble the circuit shown in Figure 5. Both lights should be lit when the proper connections have been made. This arrangement is called a parallel circuit. In this kind of circuit, current from the voltage source is divided; that is, it travels along two paths rather than along a single path. How does the intensity of the lights compare with the series circuit? How does the light intensity compare with a circuit with only one light? (17)

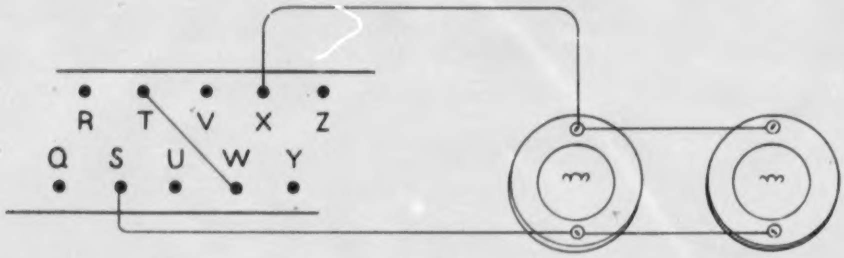


FIGURE 5: A parallel circuit.

7. Unscrew one of the lights from its holder. Does the other light go off? (18) How can this result be explained? (19) If you were wiring a house for lighting, which would you prefer to use: series or parallel wiring? Why? (20)

LABORATORY ACTIVITY C:

THE EFFECT OF RESISTANCE ON CURRENT

INTRODUCTION:

Electric current, if properly controlled, can be used for a wide variety of tasks such as lighting a light bulb, producing music on a loudspeaker or running a computer. Consequently, controlling the amount of current in a circuit is one of the most important electrical problems. We have already mentioned in Sections A and B that current is affected by both voltage and resistance. For example, increasing the voltage in a circuit also increases the current. Therefore, a light bulb glows more brightly if two flashlight batteries are used instead of one.

Resistance also can be used to control current. The purpose of this activity is to investigate the nature of the relationship between current and resistance when the voltage is kept constant. In other words, how does a change in resistance affect the current?

To answer this question, a constant voltage is applied to different lengths of a long wire, and the current flowing through the wire is measured. The source of voltage is the BIP; the BIP is also used for measuring current. The resistance in the circuit is adjusted by varying the length of the wire. Doubling the length of the wire increases the resistance by a factor of two. In other words, the resistance is directly proportional to the length of the wire. This means that our units for resistance can be expressed in units of length--in this case, in centimeters.

The data collected for the activity should list the amount of current associated with various lengths of wire. It is then possible to graph current versus the length of the wire in order to determine the effect of resistance on current.

MATERIALS:

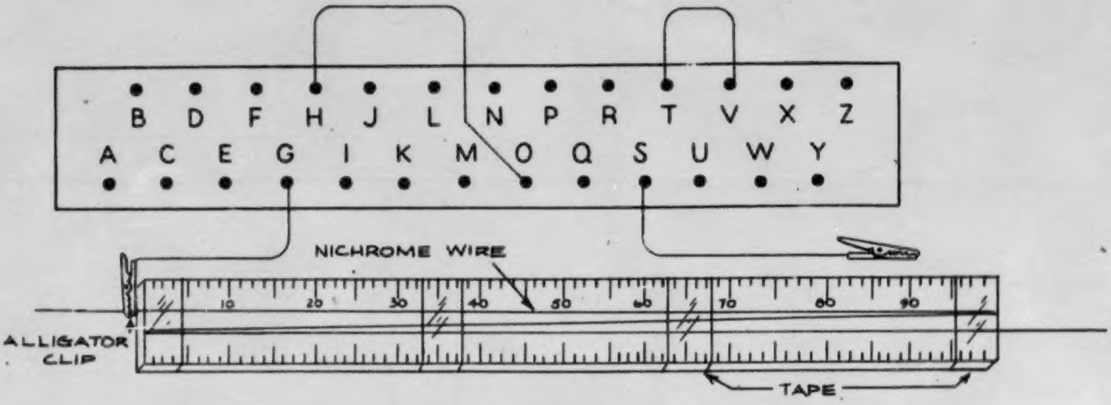
BIP
310 cm nichrome wire
connecting wire
2 connecting wires with alligator clips on one end
wire cutter-strippers
tape
meter stick

PROCEDURE:

1. Obtain a length of nichrome wire approximately 310 cm long. Tape it to a meter stick as shown in the figure on the following page. Keep the wire as straight as possible. Different parts of the wires should not touch each other. It may be desirable to tape the meter stick to the table to prevent the meter stick from moving.

2. Program the BIP as shown in the figure. Attach the alligator clip that is connected to pin G to the nichrome wire next to the "zero" on the meter stick. Plug in the BIP.

3. Touch the alligator clip that is connected to Pin S to the free end of the nichrome wire. At this point, the potential difference supplied by the BIP should be across a total length of 300 cm of nichrome wire.



4. Hold the clip firmly against the nichrome wire (it is not necessary to hold the wire between the jaws of the clip). Adjust the mA dial until the diode lights null. The reading on the dial is the current in milliamperes that is flowing through the wire. (A milliampere equals 10^{-3} amperes. Therefore, 100 mA equals 0.10 A.) Record your reading in a data sheet similar to the one shown below.

5. Move the alligator clip (connected to pin S) to a position 20 cm down the meter stick. The potential difference should now be across a total of 280 cm. Readjust the mA dial until the diode lights null. Record your reading.

6. Repeat Step 5 at different positions on the meter stick until you have a series of current readings corresponding to lengths down to 140 cm.

Length of Nichrome Wire (cm)	Current (mA)	$\frac{1}{\text{Current}}$
300		
280		
260		
160		
140		

7. Prepare a graph plotting the current readings against the length of the wire. (Since current is the dependent variable in the investigation, the current values should be plotted on the vertical axis).

8. Calculate the inverse of each of your current readings and enter these values in your data sheet. Prepare another graph plotting resistance (in terms of cm of nichrome wire) versus $(\frac{1}{\text{current}})$.

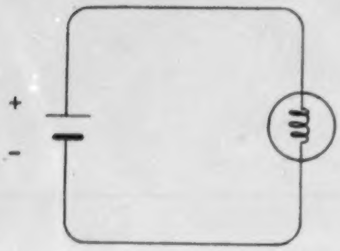
DISCUSSION QUESTIONS:

1. How is the flow of current affected by an increase in the length of the wire? by a decrease in the length of the wire?

2. From the results of the activity, does it appear that current and resistance are directly proportional, or inversely proportional? Why?

3. If the resistance of a wire is doubled, what effect does this have on the amount of current?

4. Can you think of a way to vary the brightness of the light bulb with the help of a piece of nichrome wire? Draw a diagram of your proposed circuit.



LABORATORY ACTIVITY D:

VOLTAGE AND BATTERIES

INTRODUCTION:

Batteries are convenient voltage sources since they are both portable and inexpensive. Unfortunately, batteries eventually wear out and must be replaced. This activity provides a method for determining the condition of a battery.

As has been discussed in Section A, a battery uses chemical energy to produce voltage. But the battery is not completely efficient in using chemical energy because each battery has an internal resistance. Just as energy is expended in moving electrons through a resistor, light bulb or loudspeaker, energy is also expended in moving electrons through the internal resistance of a battery. Consequently, a part of the battery's voltage is used just to keep current flowing through the battery. The voltage required to do this is referred to as the internal voltage drop of the battery.

As a battery begins wearing out, its internal resistance increases so that the internal voltage drop of the battery also increases. Eventually, the voltage drop becomes so large that the battery no longer supplies adequate voltage to the external circuit.

In this activity, batteries are tested by making two voltage measurements. First the "unloaded" voltage of the battery is determined by measuring the battery's voltage with the BIP. This measurement represents the total voltage that the battery can produce. A resistor is then connected to the battery terminals and the "loaded" voltage of the battery is measured. This measurement indicates how much voltage the battery can supply to a typical external circuit.

With these two measurements, the internal resistance of the battery may be calculated. The internal resistance provides an indication of the condition of the battery; the greater the internal resistance, the weaker the battery. The battery may be categorized as either good, marginal or very weak.

Generally, a battery in good condition may be used successfully with low-resistance circuits that drain large currents from the battery. Examples of "high-drain" circuits include flashlights and portable tape recorders. High-drain circuits do not function well using batteries in marginal condition. If a flashlight is operated with batteries in marginal condition, only a dim glow will be produced in the light bulb. However, a battery in marginal condition may still be used successfully with a "low-drain" circuit such as a transistor radio, which draws little current.

MATERIALS:

- BIP
- connecting wire
- test lead attached to 9100-ohm resistor
- assortment of 1.5-volt batteries--some new, some old
- wire cutter-strippers
- tape
- alligator clips
- 10-ohm resistor

PROCEDURE:

1. Program the BIP as shown in Figure 1. Note that the wire attached to the resistor is the positive test lead. The wire connected to X is the negative test lead.

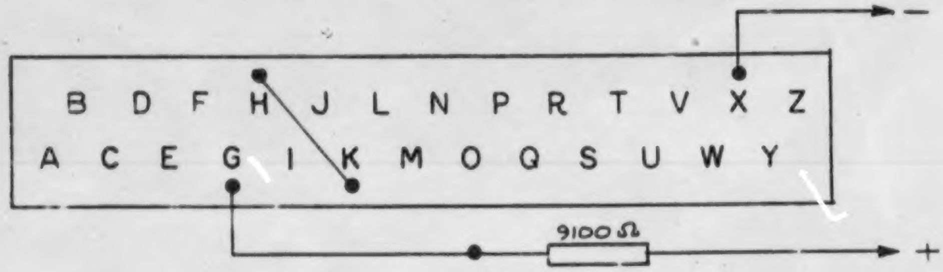


FIGURE 1: Programming the BIP to measure voltage.

2. Select a numbered battery. Record its specifications on your data sheet as follows.

battery number: the number that has been written on the battery

size: C, D or AA

type: flashlight, transistor, heavy-duty, etc.

make and model: Eveready #1050, Ray-O-Vac #1C, etc.

3. Tape the negative test lead to the negative end (the flat side) of the battery, and the positive test lead to the positive end (Figure 2). The wire is less likely to move underneath the tape if the tip is bent into a "U" shape with the wire strippers. Make sure that enough bare wire extends beyond the tape so that an alligator clip can be attached.

4. Plug in the BIP. Note that the mA dial reads from 0 to 100, which corresponds to voltages from 0 to 100 volts. Consequently, the reading on the dial must be divided by 10 to give the correct voltage.

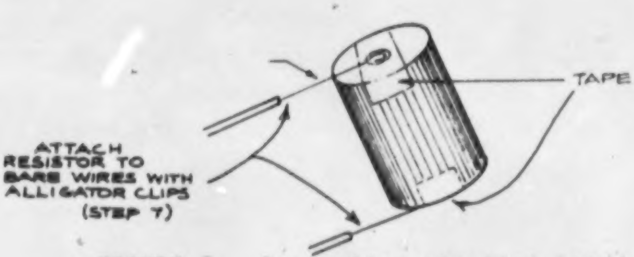


FIGURE 2: Connecting the test leads to the battery.

5. Adjust the mA dial until the diode lights null. Since the tape may not give a firm connection, apply pressure to each taped connection when taking a reading. (Note: it is important not to touch any metal parts of the circuit while making each measurement. The battery should not be resting on a metal surface.)

Divide the reading by 10 to give the voltage. Your result is the unloaded voltage (V_U) produced by the battery. If any of your voltage readings in this step or in Steps 8 or 9, are less than 1 volt (10 on the mA dial), you may make a more accurate measurement by replacing the test lead attached to the 9100-ohm resistor with a length of connecting wire. The BIP will then measure up to 1 volt--the mA-dial reading must be divided by 100 to give the correct voltage.

6. Attach alligator clips to both ends of two short lengths of wire.

7. Connect a resistor across the battery using the leads with alligator clips to connect the resistor leads to the bare ends of the test leads.

8. Measure the loaded voltage of the battery (V_L) and record your result. (Remember that metal parts of the circuit should not be in contact with you or any metal surfaces.)

9. Repeat Steps 2 through 8 with other batteries.

CALCULATIONS:

1. Use Ohm's Law to calculate the current flowing through the circuit for each battery when loaded. In this case the resistance equals 10 ohms, and the voltage is the loaded voltage (V_L) produced by the battery.

2. Calculate the internal voltage drop (V_{Int}) of each battery by subtracting the loaded voltage from the unloaded voltage ($V_U - V_L = V_{Int}$).

3. Compute the internal resistance of each battery by dividing the internal voltage drop by the current. (Note: if the loaded voltage measures 0 volts, it is not possible to compute the internal resistance of the battery. Such a battery should be considered dead.)

4. Rate the condition of the battery as either "good," "marginal," or "very weak" using the following table. The table lists the internal resistance associated with each category for each size battery.

Battery Size	INTERNAL RESISTANCE (ohms)		
	Good	Marginal	Very Weak
AA	<2.0	2.0 to 10.0	>10.0
C	<1.0	1.0 to 5.0	>5.0
D	<0.6	0.6 to 3.0	>3.0

DISCUSSION QUESTIONS:

1. How do the loaded voltages compare for new and used batteries? How do the unloaded voltages compare?

2. What appears to happen to the internal resistance as a battery wears out?

3. How is the amount of current in the circuit affected as a battery wears out? Why?

4. Felicia's protable radio is powered by four 1.5-volt batteries, connected

end to end to provide a total voltage of about 6 volts. She left it on by accident one day, and all four batteries went dead. Felicia had only three new batteries on hand, so she put those three in the radio, along with one of the dead batteries. She figured that she could get along for a while with the reception only three-fourths as strong as normal. But when she turned on the radio, she got no reception at all. Can you explain why?

LABORATORY ACTIVITY E:

MEASURING THE SKIN RESISTANCE

INTRODUCTION:

The inside of the human body is a rather good conductor of electric current. The charged particles that move in response to an applied voltage are ions of atoms such as sodium, potassium and chlorine. The body's ability to conduct current would make us very susceptible to electric shock if we did not have a protective covering of skin. In many cases where electric shock is a potential hazard, the resistance of the skin is enough to limit the flow of current to a safe level.

In this activity, you will use the BIP to measure the resistance of your skin on different parts of your hand and arm. To some extent, the resistance of the skin provides an indication of skin thickness, since thick skin resists current more effectively than thin skin. The results of the activity should give you some idea of the conditions that can permit a dangerous amount of current to flow through the body.

In order to measure skin resistance, two electrodes are attached to the body. A voltage supplied by the BIP causes a very small, harmless current to flow through the body. The amount of current flowing indicates how much the skin is resisting the flow of current. The larger the current, the lower the skin resistance. The BIP measures the amount of current: this measurement is then converted into a resistance value with the use of a table. A simplified diagram of the electric circuit used in the procedure is provided.

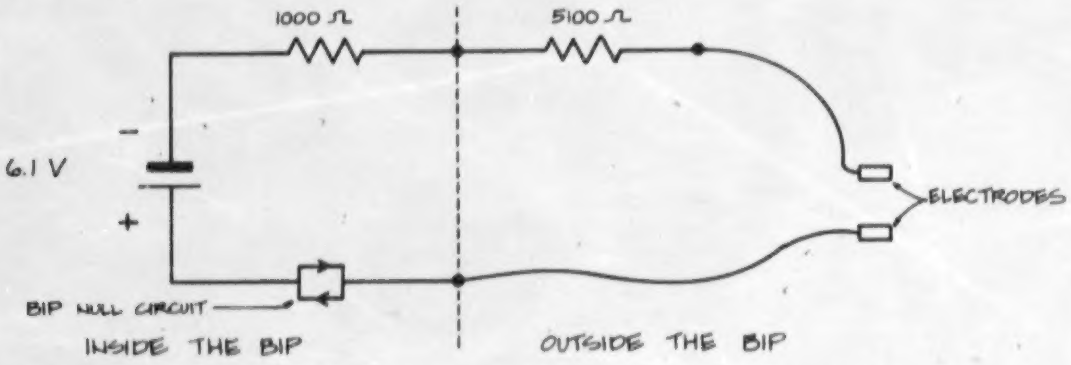


FIGURE 1: Schematic diagram for measuring skin resistance with the BIP.

The two resistors are needed for two reasons. First, a combined resistance of 6100 ohms (5100 + 1000) is needed to calibrate the BIP properly. In addition, the resistance keeps the current at a comfortable, safe level.

To begin the activity, both electrodes are placed on the skin of the arm. A diagram of the current path is shown in Figure 2. Note that the current must pass through the skin twice before returning to the BIP. Consequently, the resistance measured is actually the resistance of two skin layers (it is assumed that the resistance of the inside of the body is close to zero). To obtain the resistance of one layer of skin (R_A), the total resistance (R_T) must be divided by two. (This step assumes that the skin under each of the electrodes has approximately the same resistance.)

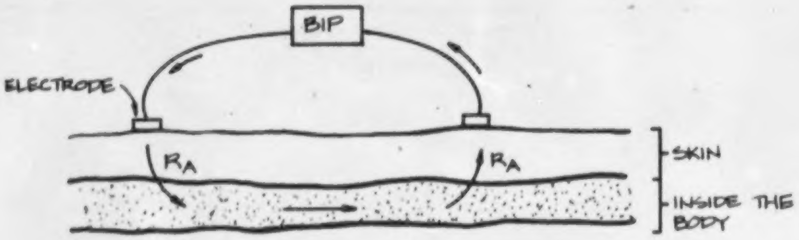


FIGURE 2: The path of the current when measuring skin resistance (R_A) on the arm.

$$\text{ARM-SKIN RESISTANCE} = R_A = \frac{R_T}{2}$$

To measure the skin resistance at other sites on the body, one of the electrodes is removed and placed on the new site. Figure 3 shows the current path when measuring the skin resistance on the palm (R_P). The skin on the palm is shown in the figure to be somewhat thicker than the skin on the arm. Once again, the current must pass through two skin layers. The total resistance (R_T) measured is therefore equal to the combined resistances of the two layers, R_A and R_P. To obtain the skin resistance of the palm, the skin resistance of the arm must be subtracted from the total resistance.

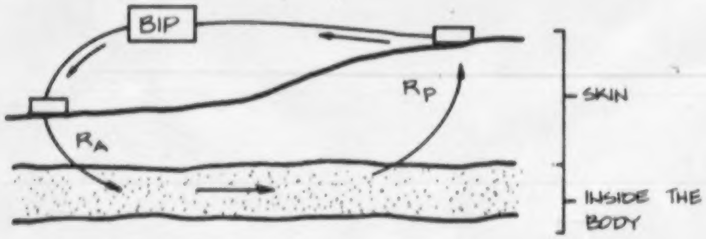


FIGURE 3: Measuring the skin resistance of the palm (R_P).

$$\text{PALM-SKIN RESISTANCE} = R_P = R_T - R_A$$

The skin resistance of other sites is determined in a similar manner.

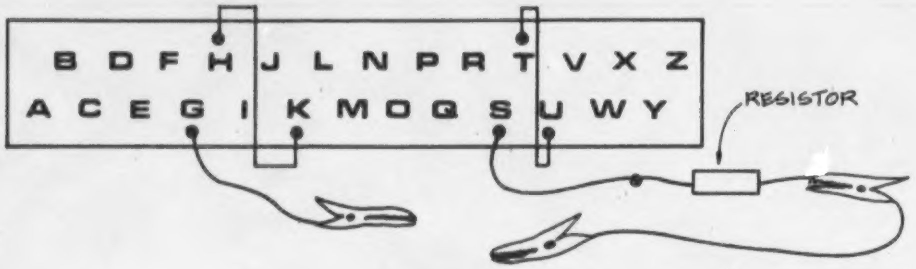
MATERIALS:

BIP
connecting wire
wire cutter-strippers
5100Ω resistor, with lead attached
3 alligator clips
2 electrodes

acetone
electrode paste
cotton or absorbent tissue
screwdriver
elastic bandage

PROCEDURE:

1. Program the BIP as shown.



2. Attach the alligator clips to the ends of the wires connected to the electrodes. Be sure the alligator clips do not touch each other, or any metal objects (except the electrode wires). Plug in the BIP.

3. Set the mA dial at 100. Touch the two electrodes together.

4. Using a screwdriver, adjust the variable voltage control (below and just to the left of the mA dial) until the diode lights null. With the electrodes not touching, the diode lights should null when the mA dial is set at or very near 0.

5. Clean an area of the inner forearm of the subject with acetone (swab with cotton or absorbent tissue). Using a small amount of electrode paste, place one electrode on that area. (The paste should not spread out and cover an area larger than the electrode.) Be sure the uninsulated side of the electrode (without the wire) is next to the skin. Secure the electrode in place with the elastic bandage. This electrode is not moved during the rest of the procedure.

6. Clean a similar area nearby on the same inner forearm and attach the other electrode, again using a small amount of electrode paste. Hold the electrode in place with your finger, touching only the plastic insulation. You may feel a slight tingling sensation on the skin. The current causing the tingling is very small and quite harmless.

7. Adjust the mA dial until the diode lights null. (Note: After each reading, remove the electrode from the skin surface to avoid possible discomfort to the subject.) Record the result in your data sheet (a sample data sheet is provided).

8. Dry the electrode with an absorbent tissue and place it on the back of the hand of the subject (same arm). Readjust the mA dial and record your result.

9. Repeat Step 8 using acetone and electrode paste.

10. Repeat Steps 8 and 9, using an area on the palm of the same hand.

11. Using acetone and electrode paste, make the same measurement for the palm of the other hand, placing the electrode at the corresponding location on the palm.

12. Repeat the procedure with other subjects.

13. Convert each of your readings to resistance values using the table provided. Enter the values in your data sheet.

14. For your first reading, the two electrodes were placed nearby one another on the same kind of skin. Assume that the skin resistance is the same at both electrodes, and that the resistance inside the body is negligible. Note that the current flows through two layers of skin. Consequently, the resistance of the forearm skin must be only half of the total resistance determined in Step 13. Enter the value for the skin resistance of the forearm in your data sheet.

15. Each of the remaining readings is also a combination of two resistances; that is, the skin resistance at the site being measured plus the forearm skin resistance. For each of the remaining readings find the desired skin resistance by subtracting the forearm skin resistance (Step 14) from the total resistance (Step 13).

16. Use the total resistance (Step 13) between the forearm and the palm of the opposite hand to determine the current that would flow through the body if connected to a 120-volt power supply. Use the equation $I = \frac{V}{R}$, and record your result.

DISCUSSION QUESTIONS:

1. If the surface area of the electrodes were doubled, what change would you expect in the current flow? How would the measured resistance change?

2. Since the predicted current (from Step 16) with 120 volts applied to the electrodes should be less than 100 milliamperes (the current needed to cause fibrilliation), how do you explain the fact that a 120-volt supply can cause death?

3. Is there any apparent correlation between skin resistance and skin thickness? Explain your answer. (Assume that the skin on the palm is slightly thicker than the skin on the back of the hand, which is slightly thicker than the forearm skin.)

SAMPLE DATA SHEET:

SITE	ELECTRODE PASTE OR DRY	mA DIAL READING	TOTAL SKIN RESISTANCE (ohms)	SKIN RESISTANCE AT SITE (ohms)
forearm	paste			
back of hand (same arm)	dry			
back of hand (same arm)	paste			
palm of hand (same arm)	dry			
palm of hand (same arm)	paste			
palm of hand (other arm)	paste			

mA DIAL READING	RESISTANCE (ohms)
0	--
1	600,000
2	300,000
3	197,000
4	146,000
5	116,000
6	95,600
7	81,000
8	70,200
9	61,700
10	54,900
11	49,400
12	44,700
13	40,800
14	37,500
15	34,600
16	32,000
17	29,800
18	27,800
19	26,000
20	24,400
21	22,900
22	21,600
23	20,400
24	19,300
25	18,300
26	17,400
27	16,500
28	15,700
29	14,900
30	14,200
31	13,600
32	13,000
33	12,400
34	11,800
35	11,300
36	10,800
37	10,400
38	9,950
39	9,540
40	9,150
41	8,780
42	8,420
43	8,090
44	7,760
45	7,460
46	7,160
47	6,880
48	6,610
49	6,350
50	6,100